GSFC 429-01-07-07

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS) PREPARATORY PROJECT (NPP)

SATELLITE ELECTROMAGNETIC INTERFERENCE (EMI) REQUIREMENTS DOCUMENT

December 11, 2001

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

INTEGRATED PROGRAM OFFICE
SILVER SPRING, MARYLAND

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NPP Satellite Electromagnetic Interference (EMI) Requirements Document

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DOCUMENT TITLE: NPP Satellite Electromagnetic Interference (EMI) Requirements Document

DOCUMENT DATE: December 11, 2001

ISSUE	DATE	PAGES AFFECTED	DESCRIPTION
Original	02/07/2002	All pages affected	Approved by CCR 429-01-07-004R1

EOS 420-CM-05 (4/92)

DOCUMENT TITLE:
NPP Satellite Electromagnetic Interference (EMI) Requirements Document

RELEASE DATE:
December 11, 2001

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1.0 INTRODUCTION

1.1 SCOPE

This Electromagnetic Interference (EMI) Requirements document defines the overall approach and design criteria to ensure compatible operation of the NPP Satellite. This document provides the EMI requirements and management organization procedures for the prime contractor, subcontractors and vendors as it relates to EMC control. The document identifies the particular requirements in the design area for bonding, grounding, and shielding to control radiated and conducted emissions and susceptibility to specified EMI/EMC levels.

General Spacecraft and Instrument EMI requirements and traceability are identified in Section 3. The system level (satellite) EMI requirements are specified in Section 4. Spacecraft component EMI requirements are specified in Section 6 and may reference paragraphs of Section 4. Instrument specific EMI requirements are specified only in Sections 1 through 3 and 5. Spacecraft ground support equipment requirements are specified in Section 7.

1.1.1 NPP Satellite Description

The NPP Satellite is comprised of the Spacecraft, VIIRS, CrIS, and ATMS. The NPP Spacecraft will provide global coverage of the Earth due to its polar orbit and will support scientific instruments for daily applications and scientific investigations. Figure 1-1 (reference only) is a diagram of the NPP Satellite showing the equipment modules required for Spacecraft housekeeping and their relationship to the Spacecraft that will support the payloads.

Planned for a late 2005 launch and a 5-year mission life, the NPP satellite is placed in an 824 km polar, sun-synchronous orbit, with an equatorial crossing time of 10:30am (+/- 10 minutes) for the descending node. The ground track repeat is less than 20 days and managed to within +/- 20 km. Pixel geo-location knowledge for surface products is planned to be 200m (3 sigma) at nadir after post-processing.

The Spacecraft Power Bus will be +28 VDC +/-TBD% with a load power requirement of TBD kW, a total Spacecraft end-of-life power requirement of TBD kW and a total solar array power of TBD kW at beginning of life. The Spacecraft is designed for single-fault tolerance.

Figure 1-1. Spacecraft Diagram (Reference Only) TBD

2.0 APPLICABLE DOCUMENTS

The applicable documents for Satellite EMI are listed in Sections 2.1 and 2.2 below and in Figure 2-1, EMI Document Tree. The documents in Section 2.3 are reference documents for the program requirements as specified in this plan. The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced below and the contents of this specification, the contents of this specification shall take precedence.

2.1 GOVERNMENT DOCUMENTS

2.1.1 Specifications

Federal

None

Military

EWR 127-1 31 October 1997	Eastern and Western Range Safety Requirements
WSMCR 160-1, Change 1 October 1985	Western Space and Missile Center Radiation 22 Program

NASA Documents

GSFC 429-00-07-01 November 2001	NPP Satellite Requirement Specification
GSFC 429-00-07-02 November 2001	NPP Satellite Mission Assurance Requirements
GSFC 429-00-07-03 June 2000	Systems Safety and Mission Assurance Requirements for the ATMS
JSC-07636 November 1975	Space Shuttle Program Lightning Protection Criteria Document, Rev A, NASA, L.B. Johnson Space Center
GSFC 429-99-04-01 28 February 2001	VIIRS Unique Instrument Interface Document (UIID)

GSFC 429-99-05-01 28 February 2001	CrIS Unique Instrument Interface Document (UIID)
GSFC 429-99-06-01 23 June 2000	ATMS Unique Instrument Interface Document (UIID)
GSFC 429-01-02-11 date (TBD)	Space Segment to Launch Support Segment Interface Requirements Document (IRD)

Integrated Program Office

Draft 6 August 2001	General Instrument Interface Document for the NPOESS and the NPP

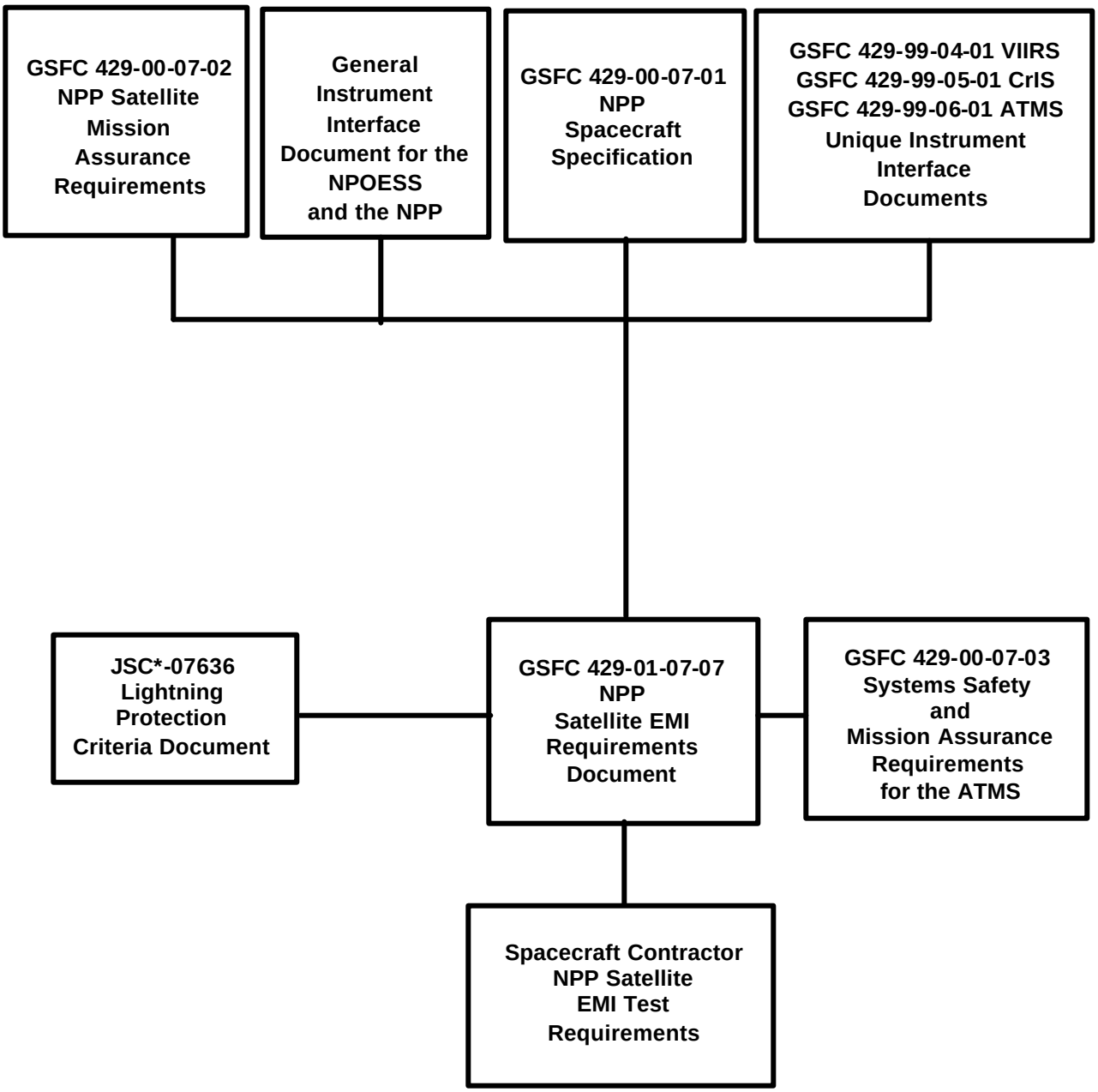

Figure 2-1. EMI Document Tree

2.1.1 Standards

Federal

NASA-STD-8739.4 February 1998	Crimping, Interconnecting Cables, Harness, and Wiring
NASA-STD-8739.3 December 1997	Soldered Electrical Connections

Military

MIL-STD-461E 20 August 1999	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-461D 11 January 1993	Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility
MIL-STD-462 11 January 1993	Measurement of Electromagnetic Interference Characteristics
MIL-STD-464 18 March 1997	Electromagnetic Environmental Effects Requirements for Systems
MIL-STD-1541A 30 December 1987	EMC Requirements for Space Systems
MIL-STD-1576, Notice 1 4 September 1992	Electro-Explosive Subsystem, Safety Requirements and Test Methods for Space Systems

Other Government Agency

None

2.1.1 Handbook

Federal

None

Military

MIL-HDBK-83575 4 June 1998	General Handbook for Space Vehicle Wiring, Harness Design and Testing

2.1.2 Drawings

None

2.1.4 Other Publications

2.2 NON-GOVERNMENT DOCUMENT

2.2.1 Specification

Spacecraft Contractor date (TBD)	NPP EMI Test Requirements

2.2.2 Standards

None

2.2.3 Drawings

None

2.2.4 Other Publications

None

2.2.5 Procedures

None

2.3 REFERENCE STANDARDS, SPECIFICATIONS, AND HANDBOOKS

GEVS-SE January 1996	General Environmental Verification Specification for STS and ELV, GFSC
NASA Reference Publication 1008 October 1977	Lightning Protection of Aircraft, Fisher and J. A. Plumer
ARP-1481	Corrosion Control and Electrical Conductivity in Enclosure Design
AFSC-DH-1-4	AFSC Design Handbook, Electromagnetic Compatibility

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3.0 EMI REQUIREMENTS

3.1 EMI REQUIREMENTS TRACEABILITY

Table 3-1 shows the traceability of EMI requirements between NPP Satellite Mission Assurance Requirements and the EMI Requirements Document.

Table 3-1. EMI Requirements Traceability

Test	MAR	EMIRD Paragraph #	Type
DC Power Leads	4.10.5	4.2, 6.2	CE
DC Power Leads	4.10.5	4.2	CE
Common Mode	4.10.5	6.2	CE
Antenna Terminals	4.10.5	6.13	CE
Magnetic Properties (System)	4.10.5	4.7	RE
Magnetic Properties (Equip)	4.10.5	6.7	RE
AC Magnetic Field (System)	4.10.5	4.1	RE
AC Magnetic Field (Equip)	4.10.5	6.1	RE
Electric Fields (System)	4.10.5	4.1	RE
Electric Fields (Equip)	4.10.5	6.1	RE
Antenna Port Emission Tx Levels	4.10.5	4.1, 6.13	RE/EMI
Antenna Port Emission Spurious	4.10.5	4.1, 6.13	RE/EMI
Power Line	4.10.5	4.4, 6.4	CS
Intermodulation Products	4.10.5	6.13	CS
Signal Rejection	4.10.5	6.13	CS
Cross Modulation	4.10.5	6.13	CS
Power Line Transients	4.10.5	4.4, 6.4	CS
Electric Fields and General EMI	4.10.5	4.3, 6.3	RS/EMI
Perform EMC with Spacecraft Tx	4.10.5	4.3, 6.3	RS/EMI
Unintentional Electric Field	4.10.5	4.3, 6.3	RS/EMI
Magnetic Field Susceptibility	4.10.5	4.3.2, 6.3.2	RS
Equip = Equipment			

3.2 EMI REQUIREMENTS APPLICABILITY

Table 3-2 shows the applicability of the EMI requirements at various levels of assembly and the specific requirement paragraph in the EMI Requirements Document.

Table 3-2. EMI Requirements Applicability (TBR)

Test	EMI RD Top Level Para. #	Level of Assembly			
		Note	Sat		Equip[6]
Conducted Emission Tests					
DC Power Leads	4.2, 6.2		X		X
Common Mode	6.2				X
Antenna Terminals	6.13				X
Radiated Emission Tests					
Magnetic Properties (System)	4.1, 4.7	4	X		
Magnetic Properties (Equip)	6.7				X
AC Magnetic Field (System)	4.1		X		
AC Magnetic Field (Equip)	6.1				X
Electric Fields System	4.1		X		
Electric Fields (Equip)	6.1				X
Antenna Port Emission (Equip)	6.13	5	X		X
Conducted Susceptibility Tests					
Power Line	4.4, 6.4		X		X
Intermodulation Products	6.13				X
Signal Rejection	6.13				X
Cross Modulation	6.13				X
Power Line Transients	4.4, 6.4		X		X
Radiated Susceptibility Tests					
Electric Fields and General EMC	4.3, 6.3	3, 4	X		X
EMC with Spacecraft Tx	4.3, 6.3	3, 4 3, 4	X X		X X
Unintentional Electric Field	4.3, 6.3		X		X
Magnetic Field Susceptibility	4.3, 6.3	2	X		X

Sat = Satellite Level
Equip = Equipment Level
Tx = Transmitters

Notes 2 Performed at system and subsystem level only
3 Definition of susceptibility defined in individual test plan per paragraph 4.3
4 System level requirement met by analysis and comparison of system and lower level of assembly test data
5 System level test performed as part of radiated EMC with Spacecraft Transmitters
6 These are the design requirements. Delineation of Qualification and Acceptance Test requirements vs level of assembly is specified in Tables 3-4 and 3-5.

3.2.1 EMI Requirements List

Table 3-3 summarizes all of the requirements contained in this EMI Requirements Document.

3.2.2 EMI Requirements Matrix

Table 3-4 tabulates the requirements contained in this EMI Requirements Document (Table 3-3) vs. the NPP equipment list.

3.3 EMI REQUIREMENTS FOR THE LAUNCH ENVIRONMENT

3.3.1 Interface EMI Requirements

The Spacecraft and its components that are active during the launch phase shall comply with the requirements in GSFC 429-00-07-02. The applicable Spacecraft operational or vulnerable elements will meet the requirements of EWR 127-1 Vol. 1, WSMCR 160-1, JSC*-07636 revision A, and GSFC 429-01-02-11.

3.3.2 Launch Phase Lightning Threat

[a] The Spacecraft Pyrotechnic circuits shall not exhibit initiation, upset, performance degradation, or failure when subjected to a lightning threat with the characteristics of Figure 3-1. The figure is derived from the Space Shuttle Lightning Protection Criteria Document (JSC*-07636) for shuttle launched Space Station items.

[b] Lightning threat analysis shall be based upon JSC*-07636.

3.4 EMI TESTING

[a] Except where specified all EMI tests shall be performed per the NPP EMI Test Requirements (TBS - Spacecraft Contractor provided). Qualification testing shall be performed per Table 3-5. The instruments shall meet the requirements of the NPP EMI Test Requirements (TBS - Spacecraft Contractor provided) in their EMI test plans.

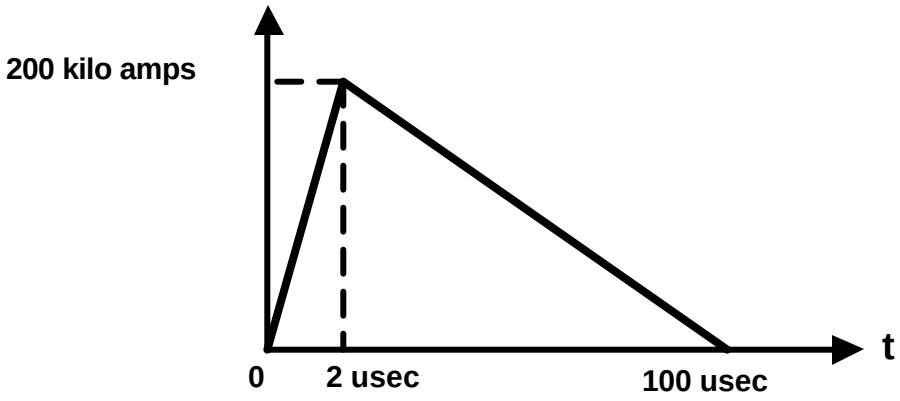
[b] The hierarchy of applicable test documents shall be, in descending order, the NPP EMI Test Requirements, GIID, and the MIL-STD-461E.

3.5 GENERAL REQUIREMENT, ELECTROMAGNETIC COMPATIBILITY

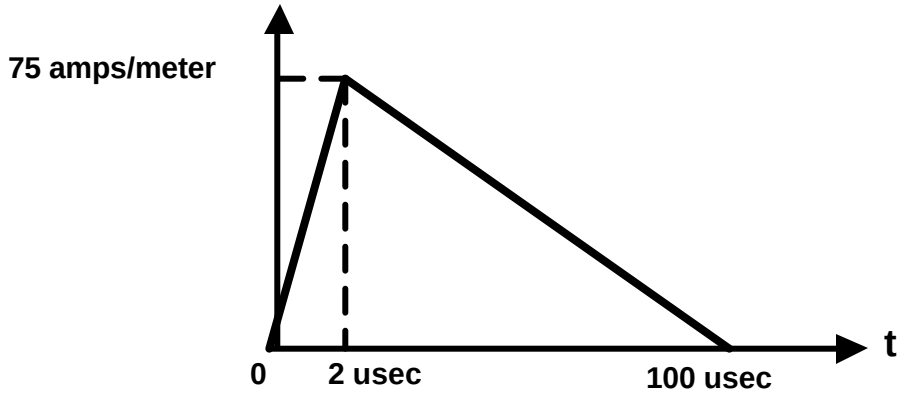
The NPP Spacecraft shall be self-compatible, compatible with its intended electromagnetic environment, and meet its EMI requirements.

Table 3-3. EMI Requirements List (TBD)

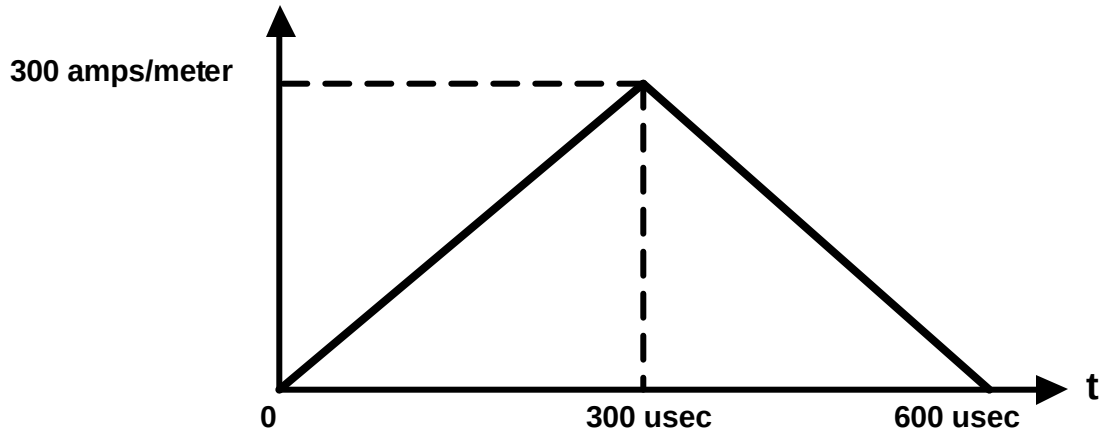
Table 3-4. EMI Requirements Matrix (TBD)



(a) Lightning current



(b) Aperture coupled field, A-component



(c) Diffusion coupled field, B-component
Figure 3-1. Lightning Threat

Table 3-5. EMI Qualification Testing (TBD)				
Subsystem	**Component**	**A Group Test**	**B Group Test**	**System Test**

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4.0 SATELLITE/SYSTEM EMI REQUIREMENTS

4.1 RADIATED EMISSIONS (RE102, RE101)

[a] The Satellite shall not radiate unintentional electric fields in excess of the limits given in Figure 4-1. Measurement bandwidths above 1 GHz may be modified, if necessary, to achieve sufficient EMI receiver sensitivity.

[b] The Satellite shall not radiate unintentional magnetic field emissions in excess of the limits specified in Figure 4-2 when measured at 1 meter.

4.2 PRIME POWER CONDUCTED EMISSIONS (CE101, CE102)

The Satellite prime power line conducted emissions shall be limited to less than the levels in Figures 4-3a and 4-3b when measured at the power distribution unit. Test measurement details will be described in separate test documents.

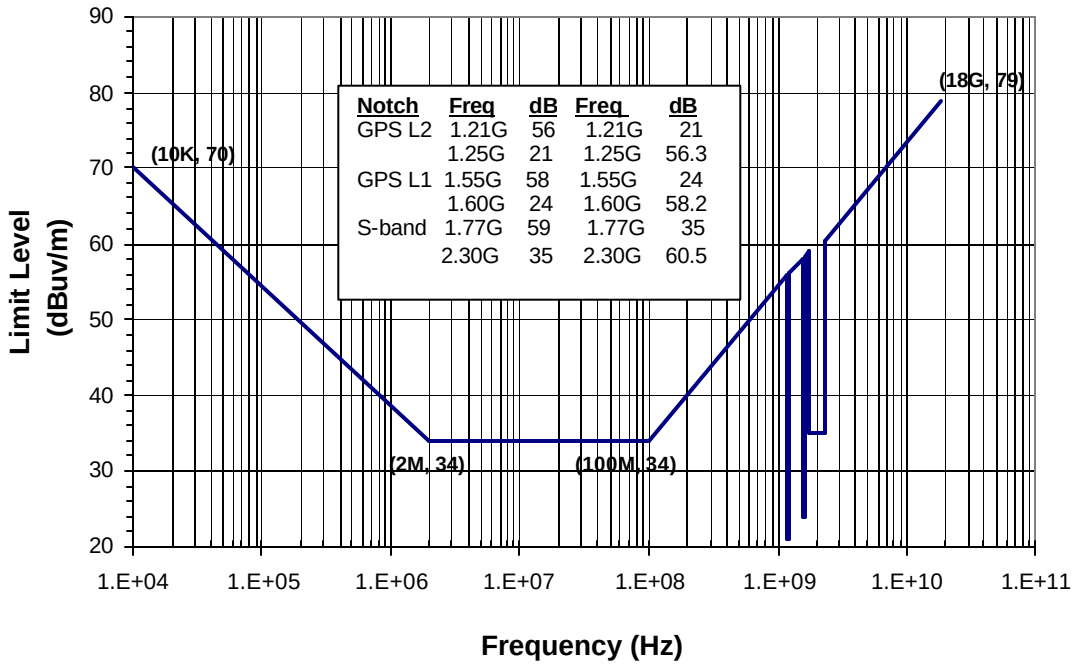


Figure 4-1. Satellite Radiated Electric Field Emissions Limits (RE102)

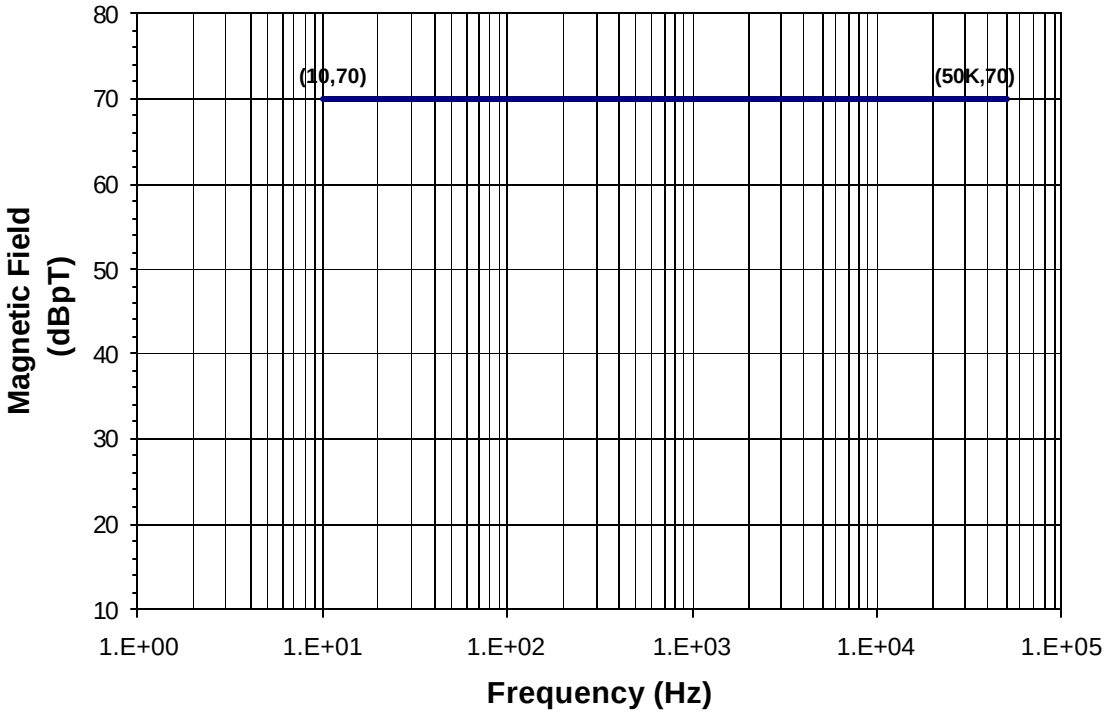


Figure 4-2. Satellite Radiated Magnetic Field Emissions Limits (RE101)

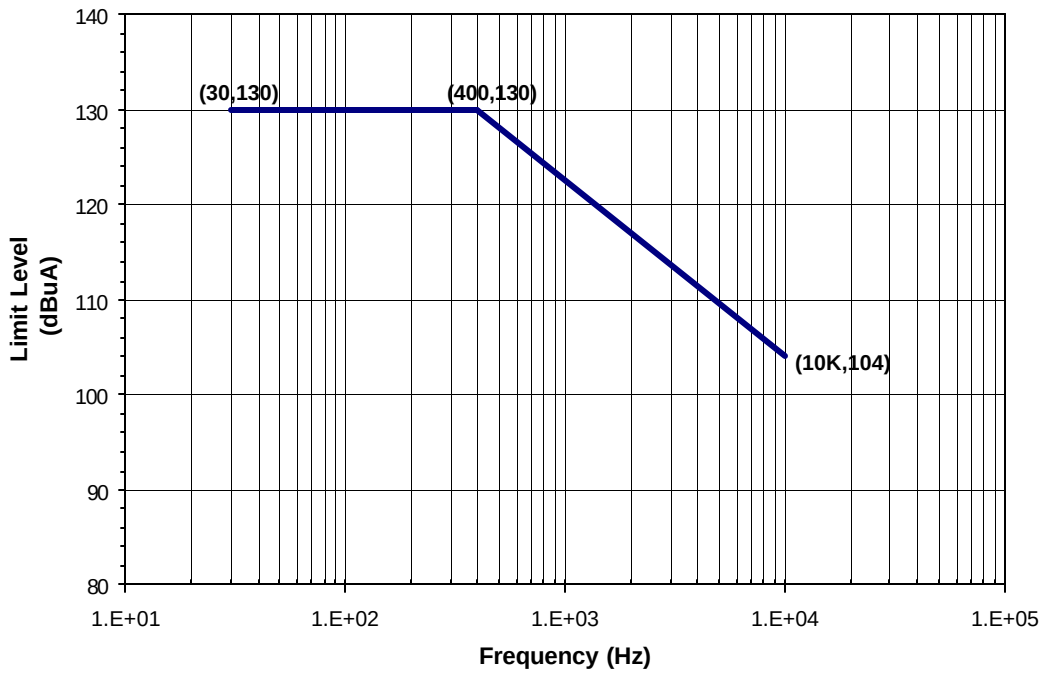


Figure 4-3-a. Satellite Prime Power Conducted Emissions Limits (CE101)

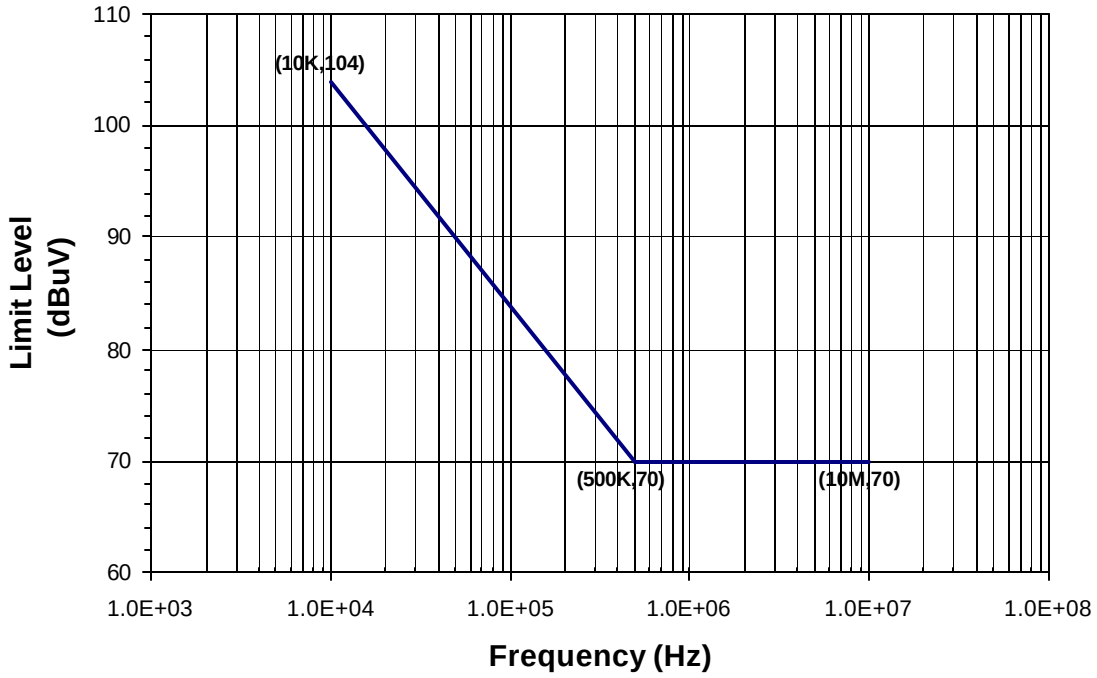


Figure 4-3b. Satellite Prime Power Conducted Emissions Limits (CE102)

4.3 RADIATED SUSCEPTIBILITY AND DEFINITION OF SUSCEPTIBILITY CRITERIA

The susceptibility criteria for the Satellite are divided into three categories. These categories are survive, operate and perform and are defined below. The applicability of the applied Environmental levels for Spacecraft equipment is detailed in Section 6.

The susceptibility criteria for Spacecraft equipment are specified in Section 6.3.

a. Survival is defined as the ability to withstand the applied environment without any permanent loss of performance capability. Survival is required for both powered and un-powered states.
b. Operate is defined as the ability to execute all functions except to take scientific data accurately in the applied environment. Operate is the ability to withstand the applied environment without malfunction, loss of capability, change of operation state/mode, memory changes or need for outside intervention. Operate requires that the survival criteria be met.
c. Perform is the ability of the Satellite to meet its specified performance. Perform requires that the Operate criteria be met.

Table 4-1. Satellite Susceptibility Requirements (TBD)

Test	Spacecraft Equipment		
	Survive	**Operate**	**Perform[5]**
RS103[1]	Y[6,4]	Y[6,4]	Y[6,4]
RS103[2]	Y	Y	Y
RS103[3]	Y	Y	Y
Magnetic Properties[7]	Y	Y	Y

Y = Applicable

(1) Composite of normal checkout, launch vehicle, and launch susceptibility levels (Figure 4-4)
(2) On-orbit susceptibility levels (Figure 4-7)
(3) Satellite generated susceptibility levels (Figure 4-5)
(4) By test or analysis
(5) Definition of susceptibility (i.e., criteria for performance) defined in test plan.
(6) Launch environment and launch environment reduced by equipment module shielding where applicable.
(7) Immunity to Satellite and Earth generated magnetic fields; verified by system self-compatibility

4.3.1 Radiated Susceptibility, Electric Fields (RS103)

a. The Satellite shall meet the following criteria when subjected to the susceptibility environments specified below.

b. The Satellite systems that are necessary for launch shall perform when subjected to electric fields over the range of frequencies and at the levels specified in Figure 4-4. Figure 4-4 is the applied maximum levels of the WSMC launch environment sources listed in Table 4-2 and the launch-vehicle-generated environment.

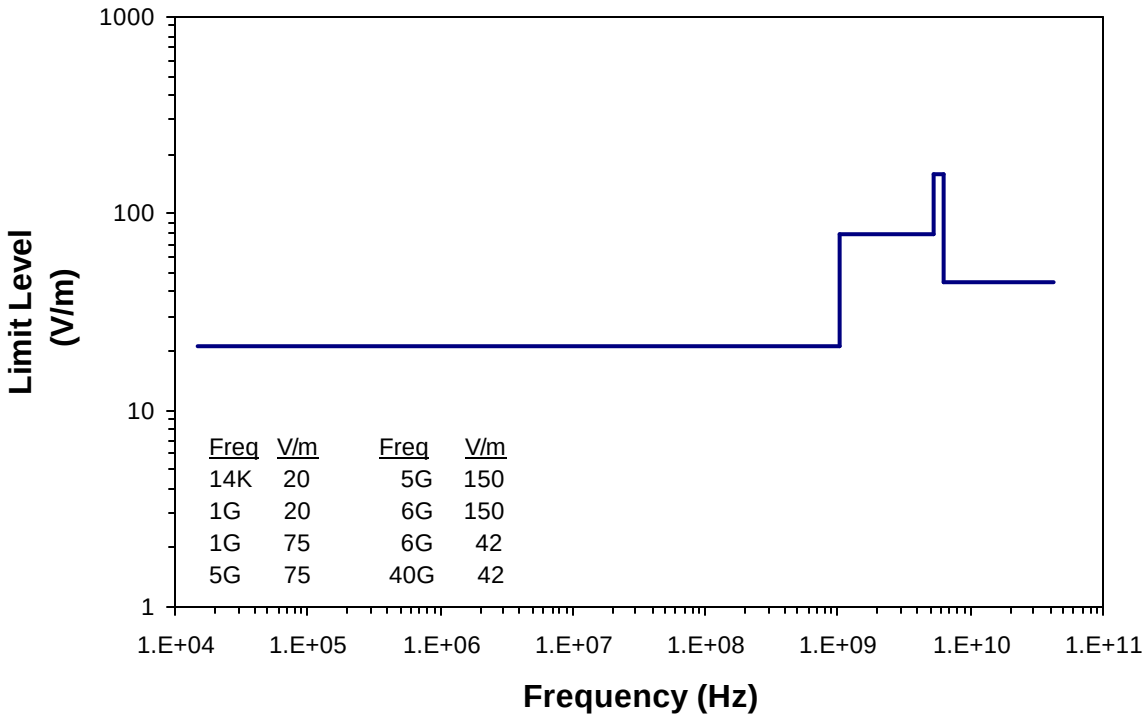


Figure 4-4. Launch Radiated Susceptibility, Electric Field (RS103)

Table 4-2. High-Level RF Sources for the NPP Satellite Launch (TBD)

Equipment	Low - High Frequency (MHz)	Peak Power (W)	Min. Power (W)	Ant. Gain (dB)	Theoretical E-Field Peak (V/m)	Measured E-Field Peak (V/m)	Avg. Intensity (V/m)	Modulation
Delta II High Level RF Environment								
S-band Telemetry	2241.5		2	2.35	20			
C-band Tracking	5765.0		400	6.00	40			

c. The Satellite systems shall survive and perform when subjected to electric fields over the range of frequencies and at the levels specified in Figures 4-4 and 4-5. The peak transmitter level in Figure 4-5 for S- and X-bands are the worst-case applied maximum level of Spacecraft sources listed in Table 4-3.

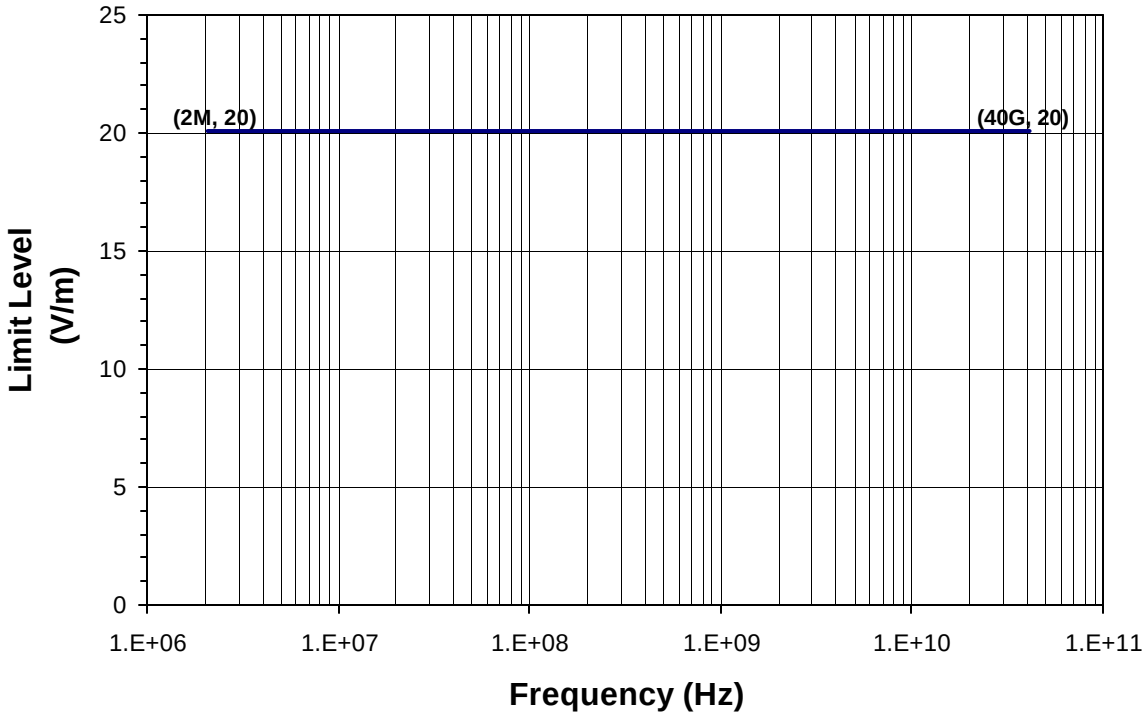


Figure 4-5. Satellite Generated Radiated Susceptibility, Electric Field (RS103)

Table 4-3. Spacecraft-Generated NPP RF Sources (TBD)

Transmitter	Band	Center Frequency (GHz)	Modulation Type	Bandwidth (MHz)	Volts/m @ Inst (E_{peak})
CDA	USB	2.2875	SQPN	3.16(2)	(TBD)
SN SSA	USB	2.2875	SQPN	3.16(2)	(TBD)
HRD DB	X	7.812	QPSK	30 (1)	(TBD)
CDA SMD	X	8.212	SQPSK	375(1)	(TBD)
SN SMD	Ku	15.0034	SQPSK	300(1)	(TBD)

(1) Width of main lobe of the transmitter spectrum (null to null).
(2) TBD

4.3.2 Radiated Susceptibility, Magnetic Fields (RS101, Static)

[a] The Spacecraft EEDs shall not be degraded after exposure to the lightning fields specified in paragraph 3.3.2. Equipment necessary for launch shall perform during exposure to the lightning fields specified in paragraph 3.3.2.

[b] The Spacecraft equipment, components, and subsystems shall perform when subjected to the Satellite magnetic field requirement of Figure 4-6.

[c] All Satellite equipment shall perform in the magnetic fields shown in Figure 4-6. Figure 4-6 shows the estimate of worst-case magnetic fields at various locations on the Satellite produced by the magnetic torque rods.

[d] The Spacecraft equipment critical and necessary for launch shall perform during exposure to a 1.5 Gauss (150 uT) Static Magnetic field.

4.3.3 Radiated Susceptibility, Electric Field On-Orbit Environment (RS103)

The on-orbit electric field levels of Figure 4-7 and Table 4-4 are the RS103 environments for the NPP orbit as reported by the Joint Spectrum Center (JSC).

The Satellite shall perform when subjected to the on-orbit electric field levels of Figure 4-7 and Table 4-4.

4.4 CONDUCTED SUSCEPTIBILITY (CS101, CS116)

Satellite level conducted susceptibility will be verified by compiling the component level test data for CS101, and CS116 to ensure that the Satellite achieves Electromagnetic Interference Safety Margin (EMISM).

4.5 NOT USED

4.6 DEPLOYMENT EED/NEA DESIGN

The Satellite design shall provide protection from premature deployment of electro-explosive devices (EEDs) and non-explosive actuators (NEA) in accordance with MIL-STD-1576.

4.7 EQUIPMENT MAGNETIC PROPERTIES

Satellite equipment static dipole moment shall not exceed 0.3 Am^2 initially and shall not exceed 0.3 Am^2 after torque rod activity. Torquer rods shall be designed to limit residual static dipole moment to 5 Am^2.

4.8 ELECTROMAGNETIC INTERFERENCE SAFETY MARGIN

The Electromagnetic Interference Safety Margin (EMISM) for safety critical circuits (such as NEAs and EEDs) shall be 20 dB, verified by analysis or test. EMISM for other EMC critical circuits shall be 6 dB, verified by comparison of emissions and susceptibility test data.

Figure 4-6. Satellite Torquer Rod Magnetic Fields (TBD)

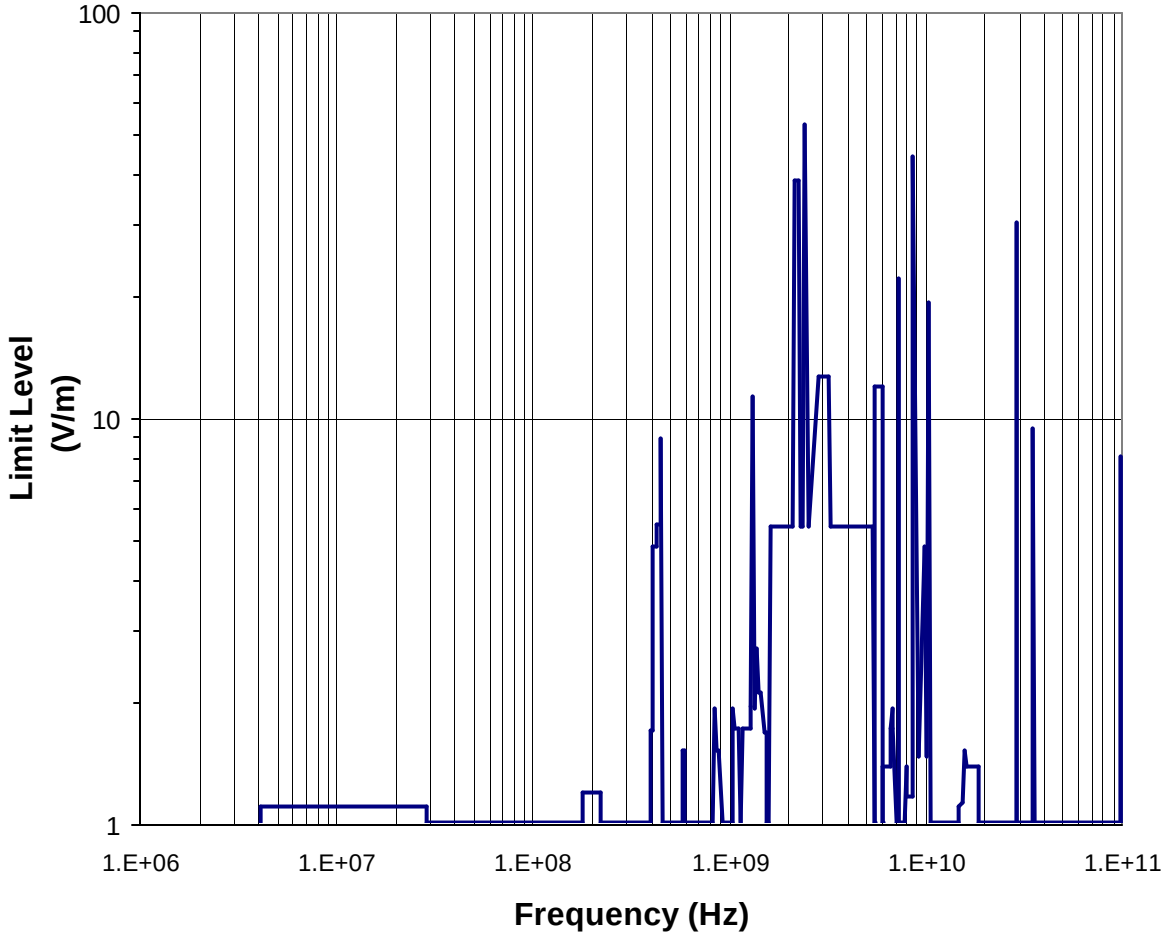


Figure 4-7. Radiated Susceptibility, Electric Field On-Orbit Environment, JSC Data (RS103) (TBD)

Table 4-4. On-Orbit Environment Electric Field Levels, JSC Data (RS103) (TBD)					
Frequency GHz	**Electric Field Volts/M**	**Frequency GHz**	**Electric Field Volts/M**	**Frequency GHz**	**Electric Field Volts/M**
0.004	1.00	1.240	1.710	6.520	1.910
0.004	1.10	1.260	1.940	6.630	1.710
0.028	1.10	1.280	11.200	6.860	1.000
0.028	1.00	1.300	1.910	7.040	1.000
0.174	1.00	1.340	2.680	7.080	21.900
0.174	1.19	1.370	2.090	7.100	1.000
0.214	1.19	1.410	2.090	7.650	1.000
0.214	1.00	1.460	1.660	7.690	1.380
0.383	1.00	1.510	1.660	7.810	1.160
0.385	1.69	1.510	1.000	8.350	1.160
0.398	1.69	1.550	1.000	8.350	43.700
0.398	4.79	1.560	5.350	8.910	1.450
0.418	4.79	2.060	5.350	9.680	4.790
0.418	5.45	2.100	38.000	9.840	1.450
0.432	5.45	2.200	38.000	10.000	19.100
0.432	8.87	2.240	5.350	10.200	1.000
0.447	1.00	2.310	5.350	14.300	1.000
0.560	1.00	2.350	52.500	14.400	1.100
0.562	1.50	2.470	5.350	15.100	1.120
0.572	1.50	2.770	12.500	15.300	1.510
0.574	1.00	3.110	12.500	15.600	1.380
0.804	1.00	3.160	5.350	18.100	1.380
0.808	1.91	5.270	5.350	18.200	1.000
0.835	1.51	5.290	1.000	28.000	1.000
0.862	1.51	5.330	1.000	28.200	30.200
0.908	1.00	5.350	11.800	28.300	1.000
1.010	1.00	5.810	11.800	34.200	1.000
1.020	1.91	5.840	1.000	34.300	9.380
1.030	1.71	5.880	1.000	34.500	1.000
1.090	1.71	5.910	1.380	94.700	1.000
1.100	1.00	6.410	1.380	95.200	7.940
1.140	1.71	6.410	1.710	95.700	1.000

4.9 SUPERPOSITION

The radiated and conducted susceptibility requirements will be superimposed on the system critical circuit under investigation to establish the EMISM. This requirement shall be verified by analysis of equipment EMI test data.

4.10 BONDING

[a] All metal components and electrical equipment shall be bonded to the Structure Grounding System (SGS).

[b] The Satellite equipment and system electrical ground shall be bonded together so that each metal-to-metal joint is $\leq$2.5 mΩ DC resistance between elements. Spacecraft metallic structural elements shall be bonded with less than 2.5 mΩ between joints. Spacecraft mechanical structures that are not part of the SGS shall be bonded together so that DC resistance is less than 10 Ω between joints.

[c] Direct bonding is preferred but movable metal-to-metal joints may use bonding straps providing $\leq$2.5 mΩ DC resistance and $\leq$100 nH inductance. Equipment shall be bonded to the SGS with redundant bonding straps. Each strap shall provide a bond of less than 2.5 mΩ and 250 nH. The straps shall not restrict equipment replacement.

[d] Thermal blankets shall be bonded to structure with less than 1.0 Ω DC resistance and $\leq$250 nH inductance (measured after installation). Each blanket shall be grounded by a minimum of two grounding tabs. All metalized layers of thermal blankets shall be bonded together with less than 3.0 Ω across all layers when measured close to, but not on, the grounding tabs. The maximum resistance between grounding tabs shall be 3.0 Ω (measured prior to installation).

[e] The Bonding surfaces will use conductive corrosion protection such as alodine for aluminum or DOW 19 for magnesium.

4.10.1 Connector and Shield Bonding

[a] Multipin connectors that utilize coaxial or triaxial contacts shall bond the overall shield contact to the interface connectors' shell with $\leq$ 10 mΩ resistance.

[b] The outer shield of all cables shall be 360 degrees bonded to the interface connector shell.

[c] The outer shield of all coaxial cables shall be bonded to the interfacing equipment cases with $\leq$2.5 mΩ resistance and $\leq$50 nH inductance.

[d] The outer shield of all twinaxial data bus cables shall be bonded to the interfacing equipment cases with $\leq$2.5 mΩ resistance and $\leq$50 nH inductance

[e] The case/outer shields of all equipment that connect to the Spacecraft harnesses shall have sufficient shielding to maintain the overall shielding performance of the interfacing cables.

[f] The case/outer shield described above shall be bonded to the SGS (directly or via local ground planes) with each bond contributing $\leq$2.5 mΩ resistance and $\leq$50 nH inductance.

[g] All connectors shall provide positive bonding mechanisms between mating connector halves and shall have conductive finishes.

[h] All connectors shall be 360 degree bonded to equipment case. EMI gaskets shall be used where necessary. Each electrical bond shall be $\leq$2.5 mΩ resistance.

4.11 GROUNDING, REFERENCES, AND ISOLATION

The NPP Satellite shall conform to the system-grounding concept in Figure 4-8.

4.11.1 Structure Grounding System

[a] The Structure Grounding System (SGS) primary structure shall have less than 2.4 mH inductance and 0.1 Ω resistance end to end.

[b] Structure members with conductive composite fibers shall be bonded to the Structure Grounding System with less than 1 kΩ.

[c] The prime power bus shall be single point referenced (grounded) with less than 2.5 mΩ DC resistance to the Structure Grounding System at the Single Point Ground (SPG). The prime power bus shall not use chassis or the SGS as power return.

[d] The prime power bus wiring shall be DC isolated from structure by at least 1 MΩ when the SGS is disconnected from the SPG.

[e] Each component, equipment case, and/or chassis shall be bonded to the Structure Grounding System via a direct connection, bond strap or local ground plane per paragraph 4.10.

4.11.2 Kinematic Mount Isolation

Kinematic mounts used for instrument mounting plates or for direct mounting shall provide greater than 10 kΩ DC isolation.

4.11.3 Thermal Blanket Grounding

[a] All metalized layers of thermal blankets shall be grounded to the Structure Grounding System either by direct connection or by bonding to a local chassis or ground plane per Paragraph 4.10.

[b] Closeout blankets between instruments on separate ground islands shall not be grounded such that the ground island concept is violated (i.e., the blankets shall not be grounded to both islands).

4.11.4 Secondary Power Referencing

[a] Each secondary power return conductor, (except when Isolated secondary power is used), shall be grounded to chassis locally thereby providing a DC reference path to the Structure Grounding System. Isolated secondary power is defined as power that is not used to power "Spacecraft to Spacecraft" interface circuits and power that is totally consumed internally.

[b] Isolated secondary circuits may use an internal single point ground system when necessary and when justified through appropriate analysis.

4.11.5 Signal Interfaces Grounding, References, and Isolation

[a] The signal grounding between equipment, mounting plates, or system elements will conform to the concept in Figures 4-9 and 4-10.

[b] All differential interface signals between equipment shall use a dedicated return conductor (twisted pair) with returns isolated from chassis. The differential interface receiver circuit shall provide 3 kΩ minimum isolation from chassis ground.

[c] RF signal circuits shall utilize coaxial circuit connections and shall be designed so as to minimize the effect of low frequency currents on the outer conductor.

[d] EEDs and other safety critical circuits shall have return conductors isolated from chassis by 2 MΩ minimum when bleeder resistors are disconnected.

[e] Equipment shall bond all data bus cable shields to chassis at the Spacecraft Interface. Data bus cable shields shall be bonded to chassis at both ends. Cable shields may be bonded to the Structure Grounding System or chassis at 1 to 3 meter spacing if necessary.

[f] Except for high-speed digital signals all interface signals with fundamental or rise time frequency components greater than 4 MHz shall require the use of coaxial cable.

[g] High-speed digital signal circuits shall be designed to maximize the use of differential.
drivers and receivers that provide a return that is isolated from chassis.

[h] Passive bi-level and passive analog telemetry sensors shall be isolated from chassis by $\leq$100 kΩ.

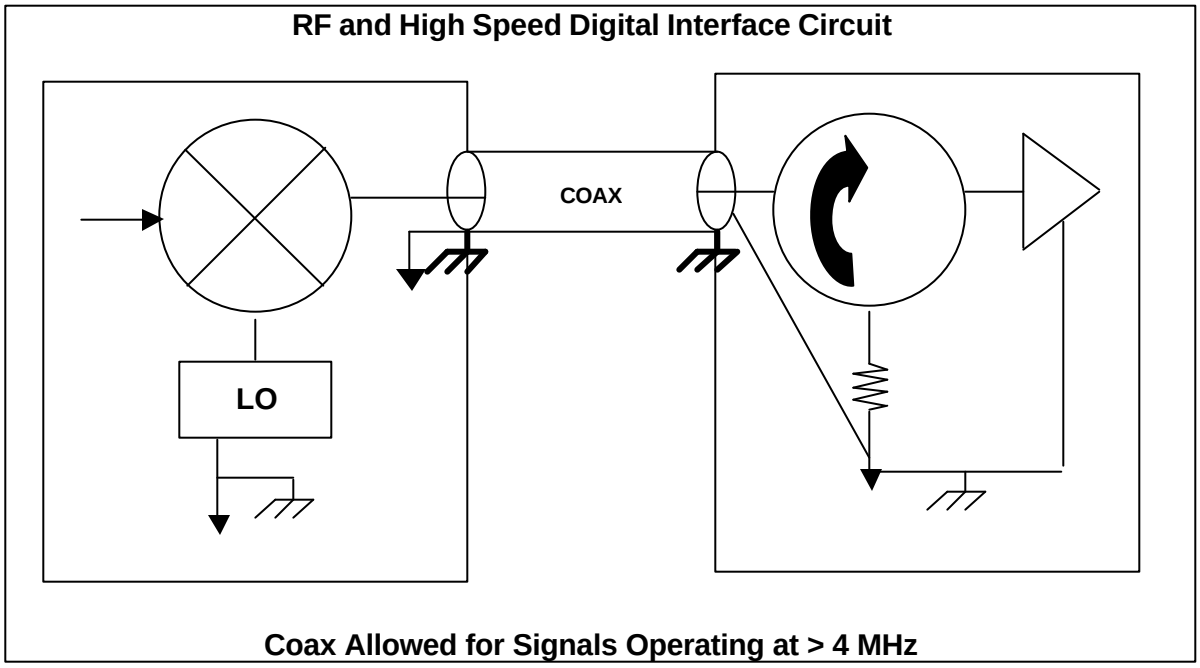
4.12 WIRING DESIGN

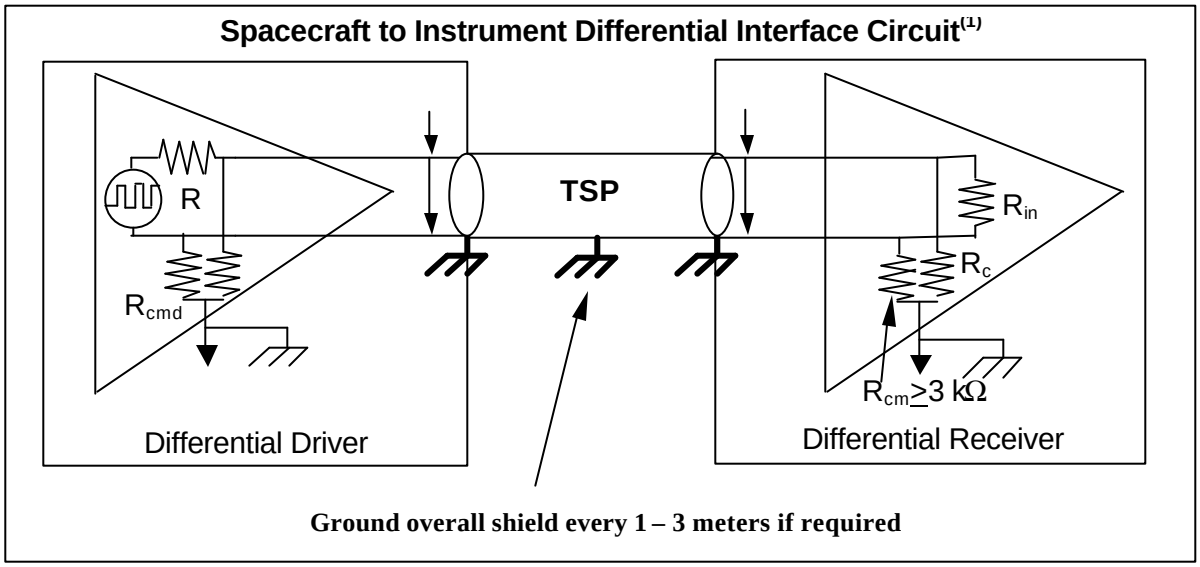
[a] The Spacecraft wiring shall be designed in accordance with NASA-STD-8739.3, NASA-STD-8739.4, and Table 4-5.

[b] The Spacecraft design shall provide wire segregation, routing, shielding and shield termination. A 30 mm separation distance between bundled cables is suggested to reduce mutual coupling between shield currents. The GIID should be used as a reference for definitions of signal types.

Figure 4-8. Satellite Grounding Concept (TBD)

Figure 4-9. Secondary Electronics Grounding and Data Interface Concept (TBD)





(1) This circuit is RS422 compatible.

Figure 4-10. Interface Signal Grounding (TBD)

Table 4-5. Wire Design Requirements (TBD)				
Group Designation	**Spacecraft Signal Type**	**Wire Type**	**Minimum Shielding**	**Shield Termination**
Ia	28 VDC Power	Twisted conductor	OBS	360 @ Backshell
Ib	Secondary Power	Twisted conductor	OBS	360 @ Backshell
IIIa	Analog TLM, Active	Twisted Pair	OBS	360 @ Backshell
IIIb	Analog TLM, Passive	Twisted Pair*	OBS	360 @ Backshell
Ic	Relay Drive Commands	TC (1 Rtn/8 leads with > 2 rtn's /connector)	OBS	360 @ Backshell
Ic	Logic Level Commands	Twisted Pair	OBS	360 @ Backshell
IIIc	Bi-level TLM, Passive	Twisted Pair*	OBS	360 @ Backshell
IIb	Bi-level TLM, Active	Twisted Pair	OBS	360 @ Backshell
Vc	Time Mark and Freq. Bus	Twinax, Similar to Gore CXN2207	2S	360 @ Triaxial Conn.
Vb	Command and TLM Bus	Twinax, Raychem 7724C8664	3S	360 @ Triaxial Conn.
Vb	Science Data (Low Rate)	Twinax, Raychem 7724C8664	3S	360 @ Triaxial Conn.
IIId	Science Data (High Rate) 1394a	TBD	TBD	TBD
Va	RF/uWave	Coax/waveguide	2S Foil/Braid	360 @ SMA Conn.
IV	EED (Pyro)	1STP	Wrap bundle	360 @ Backshell

Notes:

OBS = Overall bundle shield; **TC** = Twisted conductor **Coax** = Coaxial cable; **Twinax** = Controlled impedance twisted shielded pair; **1S** = Single shield; **2S** = Double shield; **3S** = Triple shield; **TLM** = Telemetry; * = May be shielded based on location; **Conn.** = Connector

Group designations defined in MIL-W-83575A.

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5.0 INSTRUMENT EMI REQUIREMENTS

5.1 REQUIREMENTS

The Instrument requirements are contained in the General Instrument Interface Document (GIID). Only the requirements for instruments that are on the NPP Spacecraft shall be applicable.

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6.0 EQUIPMENT/SUBSYSTEMS EMI REQUIREMENTS

6.1 EQUIPMENT RADIATED EMISSIONS (RE102, RE101)

[a] Spacecraft equipment, subsystems and components shall not radiate unintentional electric fields in excess of the limits given in Figure 6-1 and to the levels specified in the GIID for the NPP instruments. Measurement bandwidths above 1 GHz may be modified, if necessary, to achieve sufficient EMI receiver sensitivity.

[b] Spacecraft equipment, subsystems and components shall limit unintentional magnetic field emissions to within the limits specified in Figure 6-2 measured at 1 meter.

6.2 EQUIPMENT CONDUCTED EMISSIONS (CE102, CECM)

[a] Spacecraft equipment, subsystems and components (except the power subsystem) shall limit prime power conducted emissions to levels less than or equal to those shown in Figure 6-3.

[b] Spacecraft equipment, subsystems and components (except the power subsystem) shall limit prime power common mode conducted emissions to levels less than or equal to those shown in Figure 6-4.

[c] Repetitive spikes shall meet the conducted emission requirements for CW signals.

6.3 RADIATED SUSCEPTIBILITY AND DEFINITION OF SUSCEPTIBILITY CRITERIA

The susceptibility criterion for spacecraft equipment has been divided into three categories. These categories are survive, operate and perform and are defined as follows.

a. Survival is defined as the ability to withstand the applied environment without any permanent loss of performance capability. Survival is required for both powered and unpowered states.

b. Operate is defined as the Spacecraft equipments ability to withstand the applied environment without malfunction, loss of capability, change of operation state/mode, memory changes or need for outside intervention. Operate requires that the survival criteria be met.

b. Perform is the ability of Spacecraft equipment to meet its specified performance. Perform requires that the Operate criteria be met.

The applicability of the above performance criteria versus the applied Environmental levels for Spacecraft equipment is detailed in Table 6-1.

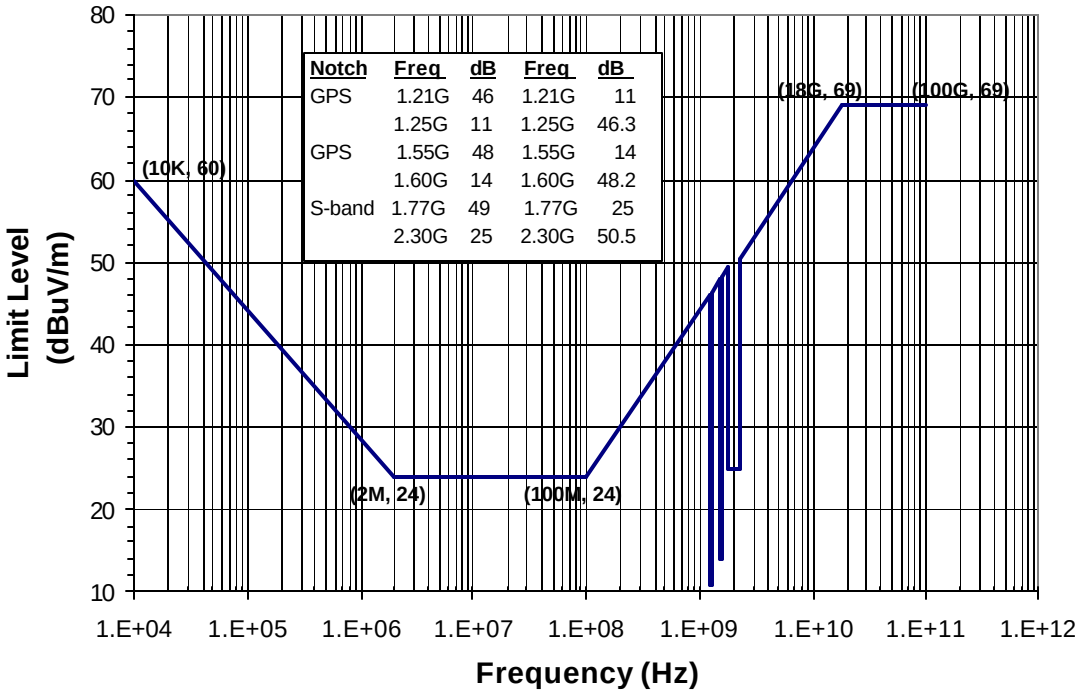


Figure 6-1. Equipment Radiated Electric Field Emissions Limits (RE102)

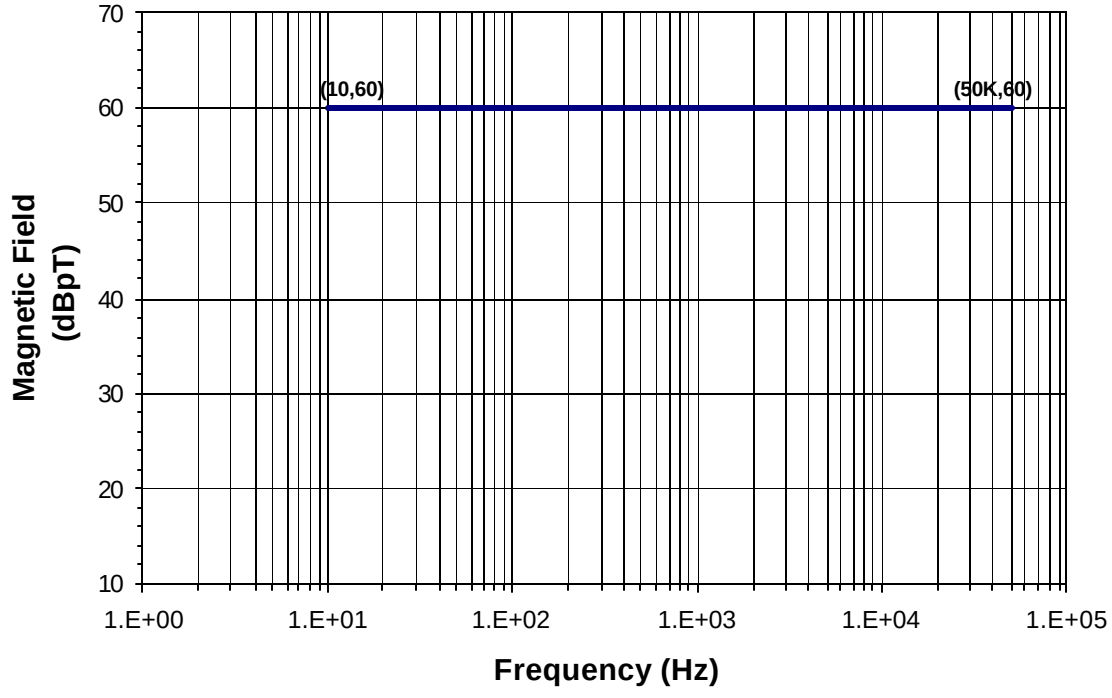


Figure 6-2. Equipment Radiated Magnetic Field Emissions Limits (RE101)

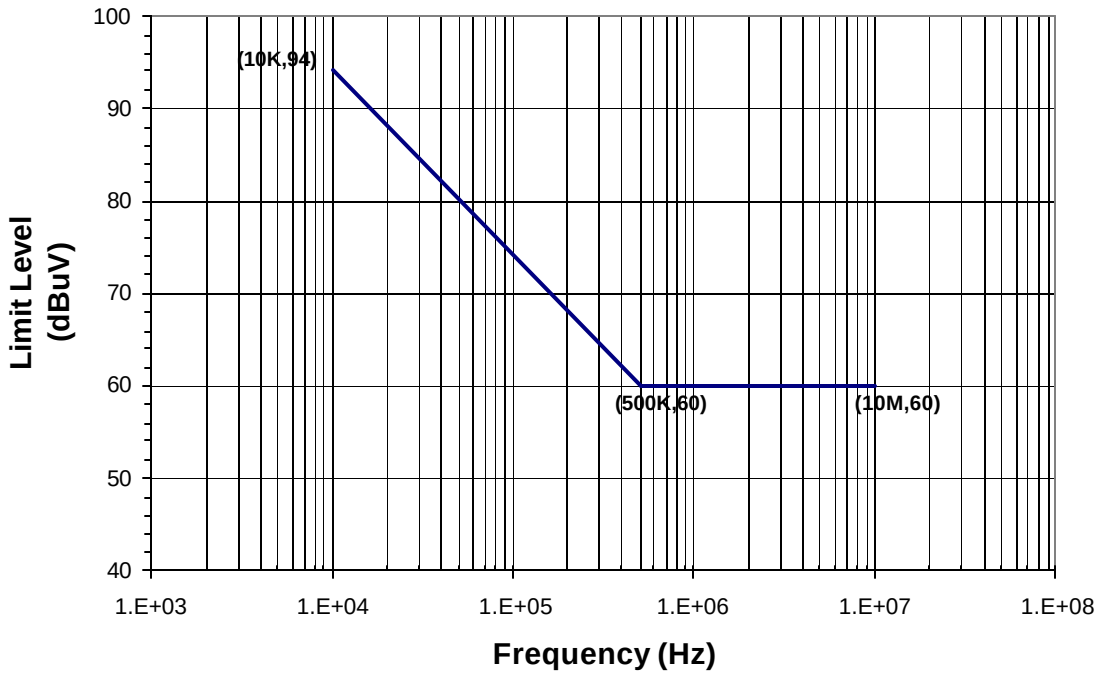


Figure 6-3. Equipment Conducted Emissions Limits (CE102)

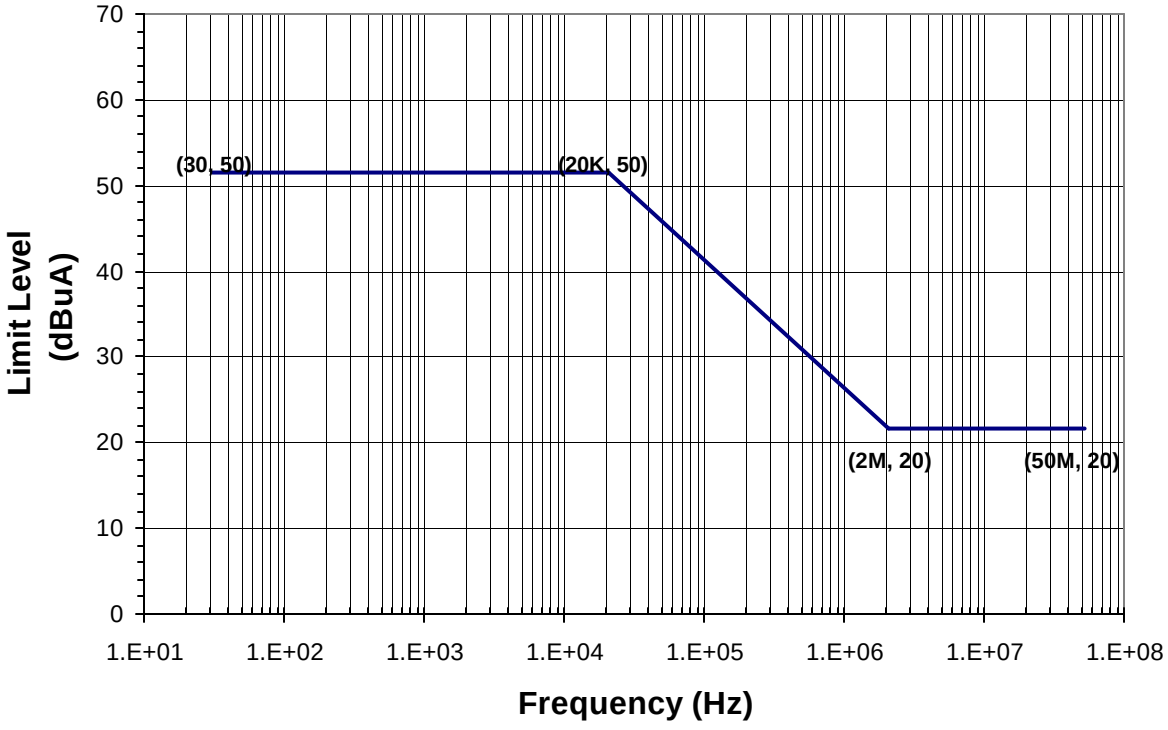


Figure 6-4. Equipment Common Mode Conducted Emissions Limits (CECM)

Table 6-1. Equipment Susceptibility Requirements (TBD)		
Test	Spacecraft Equipment	
	Survive	Perform[5]
CS101	Y	Y
CS116	Y	Y
CS103	Y	Y
CS104	Y	Y
CS105	Y	Y
RS101	Y	Y
RS103[1]	Y[6,4]	Y[6,4]
RS103[2]	Y[4]	Y[4]
Magnetic Properties[7]	Y	Y
Y = Applicable		
[1] Composite of normal checkout, launch vehicle, and launch susceptibility levels (Figure 6-6) [2] Equipment susceptibility levels (Figure 6-5) [4] By analysis or test [5] Definition of susceptibility (i.e., criteria for performance defined in test plan) [6] Launch environment reduced by equipment shielding where applicable [7] Immunity to Spacecraft and Earth generated magnetic fields, Box level test		

6.3.1 Equipment Electric Fields Radiated Susceptibility Limit (RS103)

[a] Spacecraft equipment/subsystems and components shall perform when subjected to the susceptibility environments specified in Figure 6-5.

[b] Spacecraft equipment and core harness necessary for launch shall perform when subjected to electrical fields over the range of frequencies and levels specified in Figure 6-6. Figure 6-6 is the applied maximum levels of the WSMC launch environment and the launch vehicle generated environment.

6.3.2 Radiated Susceptibility, Magnetic Fields (RS101, Static)

[a] The Spacecraft equipment, subsystems and components shall perform when subjected to the AC magnetic fields specified in Figure 6-7 and the Spacecraft magnetic field requirement of Figure 6-8.

[b] The Spacecraft equipments critical and necessary for launch shall perform during exposure to a 1.5 Gauss (150 uT) Static Magnetic field. Figure 6-8 shows the estimate of worst case magnetic fields at various locations on the Spacecraft produced by the magnetic torque rods.

[c] All Spacecraft equipment shall operate in the magnetic field levels shown at the various locations in Figure 6-8. The magnetic fields will be updated as more information becomes available and will be incorporated into this document via a Configuration Change Request (CCR).

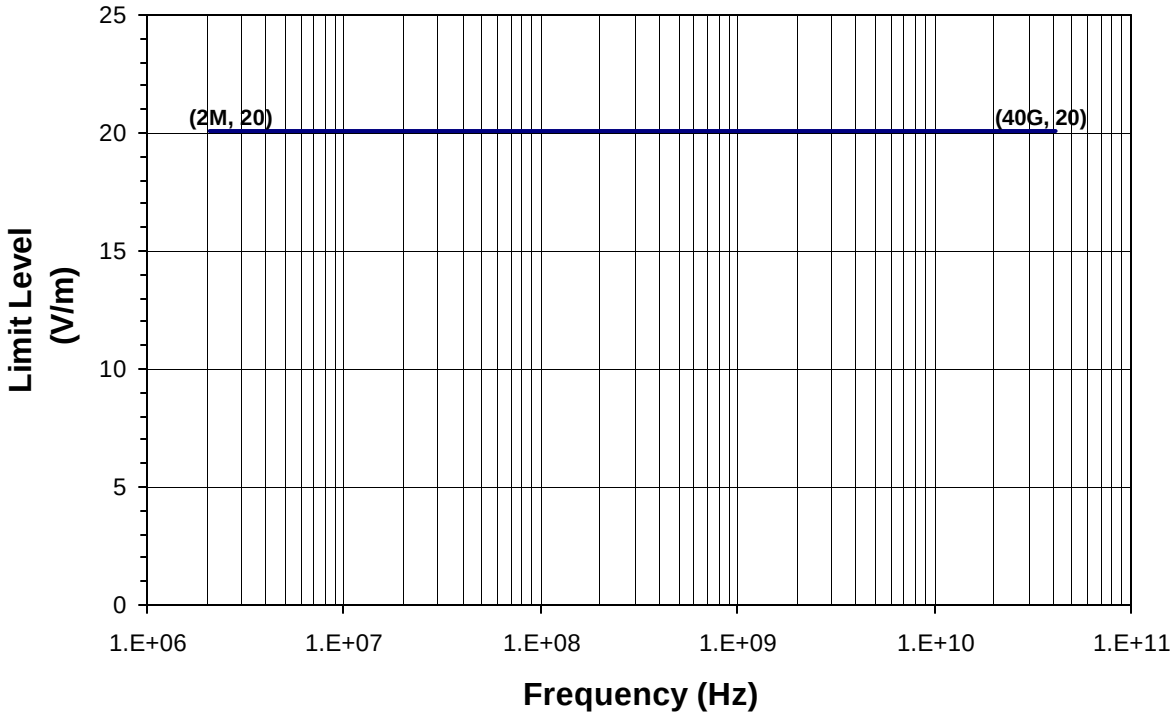


Figure 6-5. Equipment Radiated Susceptibility, Electric Field (RS103)

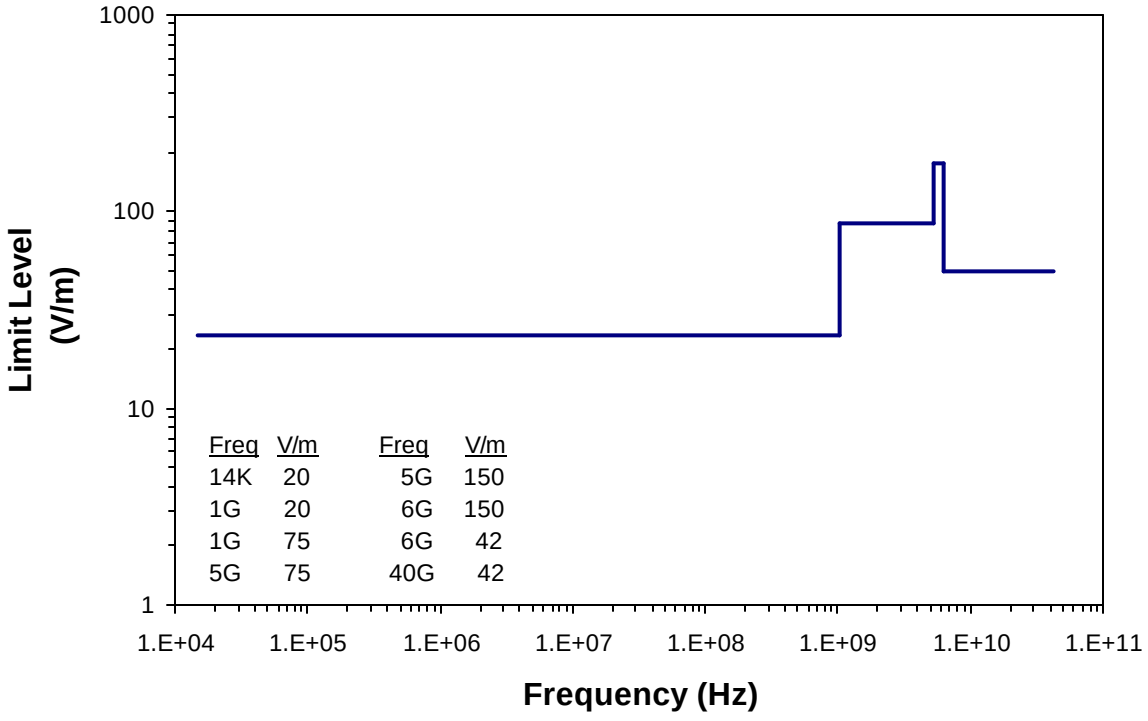


Figure 6-6. Launch Radiated Susceptibility, Electric Field (RS103)

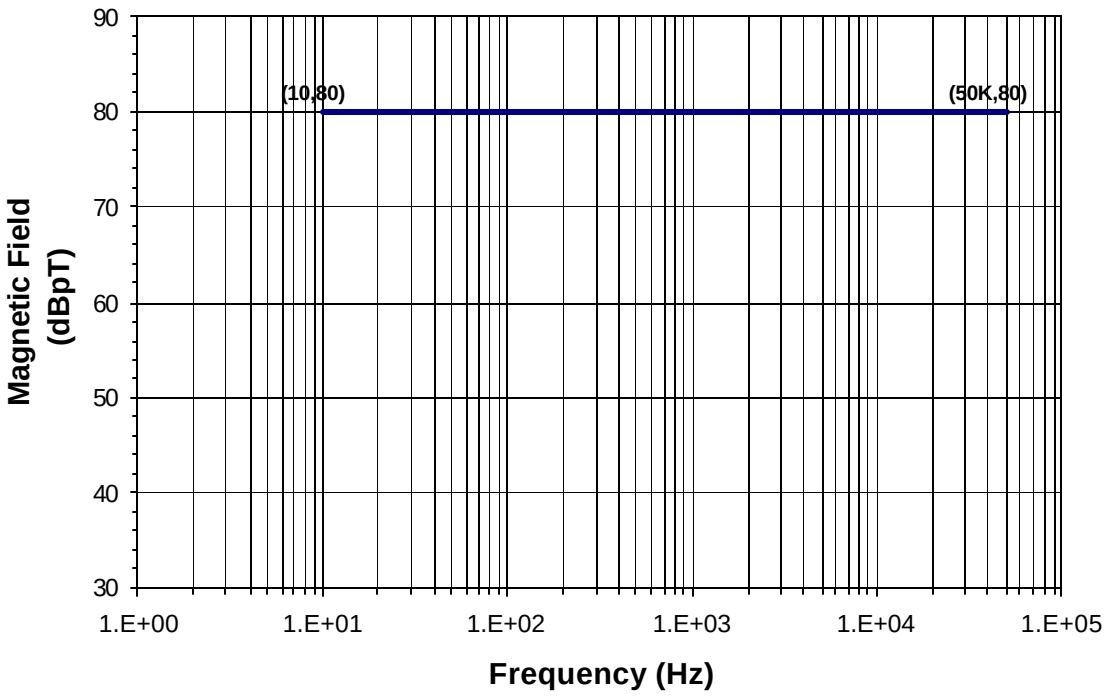


Figure 6-7. Equipment Radiated Susceptibility, Magnetic Field (RS101)

Figure 6-8. Spacecraft Torquer Rod Magnetic Fields (TBD)

6.3.3 Communication Equipment Susceptibility Requirements/Definition of Susceptibility

The Spacecraft Communication Equipment shall meet the requirements of paragraph 6.3.1 except where radiated energy is induced directly in the operating band of the equipment. Under these conditions the equipment shall operate when the environment of Figure 6-5 is applied. Additionally, no damage or permanent loss performance shall result from the susceptibility environment of Figure 6-6.

6.4 CONDUCTED SUSCEPTIBILITY (CS101, CS116)

[a] Prime powered Spacecraft components, equipment and subsystems shall perform when subjected to conducted sinewave and pulse noise (CS101) injected on the primary power bus input per Figure 6-9. Alternative means of meeting this requirement are detailed in the EMI Test Requirements, Spacecraft Contractor (TBD).

[b] Prime powered Spacecraft components, equipment, and subsystems shall perform when subjected to both positive and negative transients (CS116) injected on the primary power bus (line-to-line) per Figure 6-10a.

[c] Prime powered Spacecraft components, equipment, and subsystems shall survive when subjected to positive polarity fuse blow/fault transients injected on the primary power input leads (line-to-line, +28 V line-to-line chassis, and return-to-chassis) as shown in Figure 6-11. This requirement applies with the unit operating (powered) and nonoperating (unpowered). Testing to this requirement, to verify compliance, shall be restricted to nonflight hardware.

[d] Prime powered Spacecraft components, equipment and subsystems that must operate through all safe modes shall operate when subjected to transient noise (fuse blow/fault transient, CS116 - Survive) injected on the primary power bus per Figure 6-11 and paragraph [c], above.

[e] Equipment powered from secondary voltages less than 23 volts shall perform when sinewave and transient noise scaled to the ratio of secondary voltage divided by the primary voltage is applied to their power input.

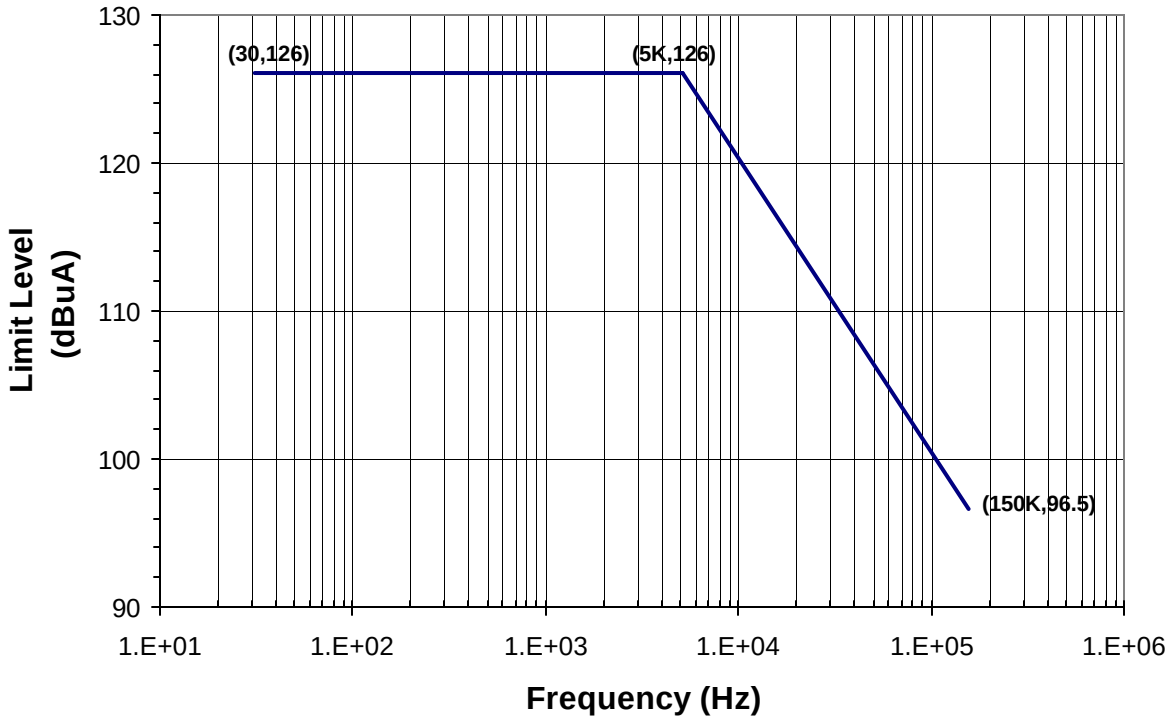


Figure 6-9. Equipment Conducted Susceptibility (CS101)

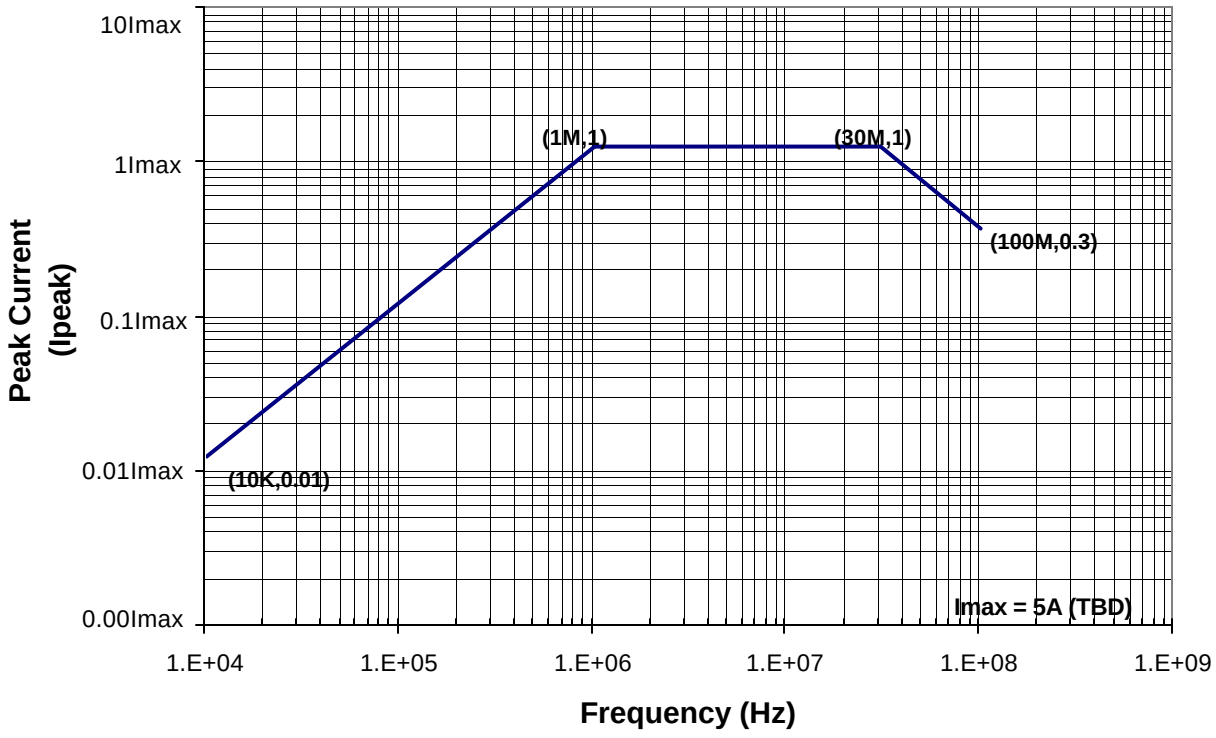
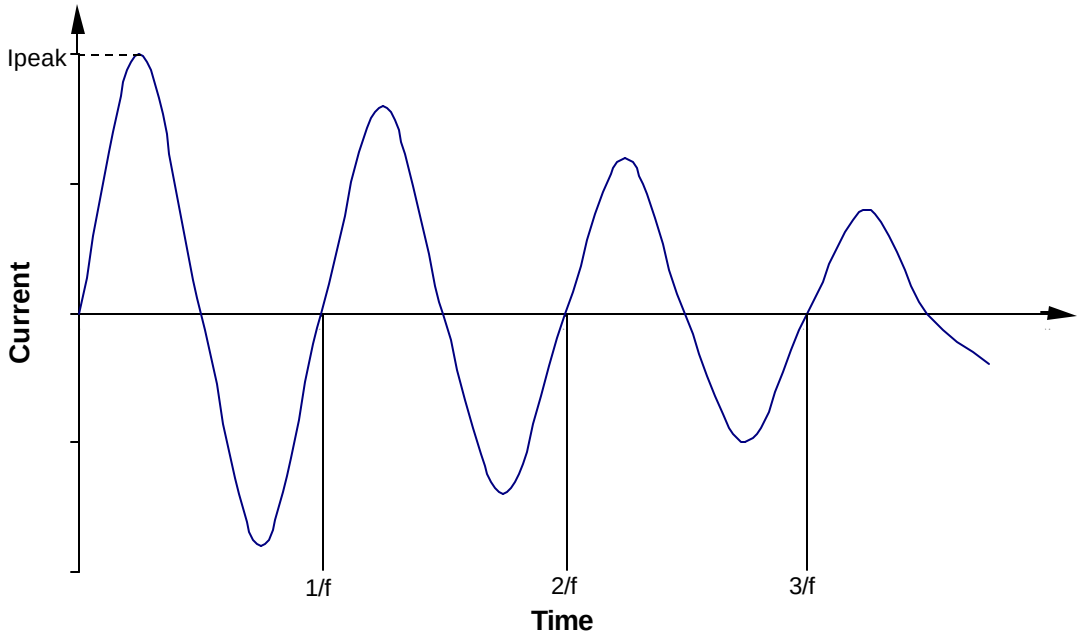


Figure 6-10a. Equipment Conducted Transient Susceptibility (CS116 – Operate)

CHECK THE NPP WEBSITE AT http://jointmission.gsfc.nasa.gov TO VERIFY THAT THIS IS THE CORRECT VERSION PRIOR TO USE.



NOTES:

1. Normalized waveform: $e^{-(\pi ft)/Q}\sin(2\pi ft)$

   Where:
   f = Frequency (Hz)
   t = Time (sec)
   Q = Damping factor, 15 ± 5

2. Damping factor (Q) shall be determined as follows:

   $$Q = \frac{\pi(N-1)}{\ln(I_P/I_N)}$$

   Where:

   Q = Damping factor
   N = Cycle number (i.e. N = 2, 3, 4, 5, ...)
   I_P = Peak current at 1st cycle
   I_N = Peak current at cycle closest to 50% decay
   ln = Natural log

3. I_P as specified in Figure 6-10a

Figure 6-10b. Equipment Conducted Susceptibility, Damped Sinusoidal Transient Limit (CS116 - Operate)

Figure 6-11. Equipment Conducted Fuse Blow/Fault Transient Susceptibility Limit (CS116 – Survive) (TBD)

6.5 DEPLOYMENT EED/NEA DESIGN

The Spacecraft design shall provide protection from premature deployment of non-explosive actuators (NEAs) and electro-explosive devices (EEDs) in accordance with MIL-STD-1576A.

6.6 EQUIPMENT MAGNETIC PROPERTIES

Spacecraft equipment, except torque rods, static dipole moment shall not exceed 0.3 Am^2 initially and shall not exceed 0.3 Am^2 after torque rod activity. Torque Rods shall be designed to limit residual static dipole moment to 5 Am^2.

6.7 ELECTROMAGNETIC INTERFERENCE SAFETY MARGIN

The Electromagnetic Interference Safety Margin (EMISM) for safety critical circuits (such as EEDs) shall be 20 dB, verified by analysis or test. EMISM for other EMC elements shall be 6 dB, verified by comparison of emissions and susceptibility test data.

6.8 SUPERPOSITION

The radiated and conducted susceptibility requirements will be superimposed on the system critical circuit under investigation to establish the EMISM. This requirement shall be verified by analysis of equipment EMI test data.

6.9 EQUIPMENT BONDING

The Spacecraft equipment shall conform to the requirements as specified in paragraph 4.10.

6.9.1 Connector and Shield Bonding

The Spacecraft equipment shall conform to the requirements as specified in paragraph 4.10.1.

6.10 EQUIPMENT GROUNDING, REFERENCES, AND ISOLATION

The Spacecraft equipment shall conform to the requirements as specified in paragraph 4.11.

6.11 EQUIPMENT INTERFACE WIRING AND HARNESSING

[a] The Spacecraft harness shall comply with the requirements in Sections 4.10, 4.11, and 4.12.

6.12 ANTENNA PORT CONDUCTED EMISSIONS (CE106)

[a] The Spacecraft receiver and transmitter subsystems shall limit antenna port conducted emissions to the levels specified below. The emissions limits apply at the coax or waveguide port that connects to each antenna after subsystem components such as diplexers, isolators, or couplers and includes signal transmission line sections.

[b] For equipment using waveguide, the requirement shall not apply below eight-tenths of the waveguide's cutoff frequency.

[c] The Spacecraft S-band receiver and transmitter subsystems shall limit antenna port conducted emissions to the levels specified in Figure 6-12.

[d] The Spacecraft X-band CDA receiver and transmitter subsystems shall limit antenna port conducted emissions to the levels specified in Figure 6-13.

[e] The Spacecraft X-band HRD transmitter subsystem shall limit antenna port conducted emissions to the levels specified in Figure 6-14.

[f] The Spacecraft Ku-band SMD transmitter subsystem shall limit antenna port conducted emissions to the levels specified in Figure 6-15.

6.13 RECEIVER ANTENNA PORT CONDUCTED SUSCEPTIBILITY REQUIREMENTS (CS103, CS104, CS105)

[a] The Spacecraft S-band subsystem/equipment shall not respond to or exhibit degraded performance by intermodulation, rejection of undesired signals, or cross-modulation when subjected to the CS103, CS104 and CS105 methods in MIL-STD-461E.

[b] The Spacecraft X-band subsystem/equipment shall not respond to or exhibit degraded performance by intermodulation, rejection of undesired signals, or cross-modulation when subjected to the CS103, CS104 and CS105 methods in MIL-STD-461E.

[c] The Spacecraft Ku-band subsystem/equipment shall not respond to or exhibit degraded performance by intermodulation, rejection of undesired signals, or cross-modulation when subjected to the CS103, CS104 and CS105 methods in MIL-STD-461E.

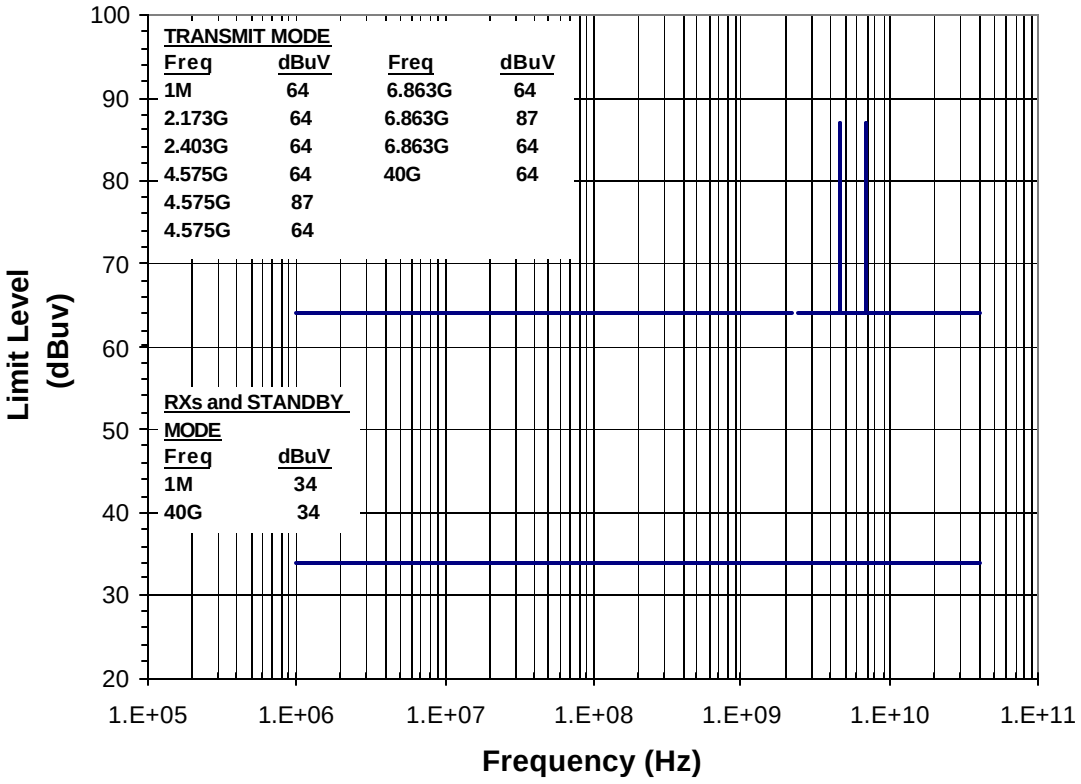


Figure 6-12. S-Band Antenna Port Emissions (CE106) (TBD)

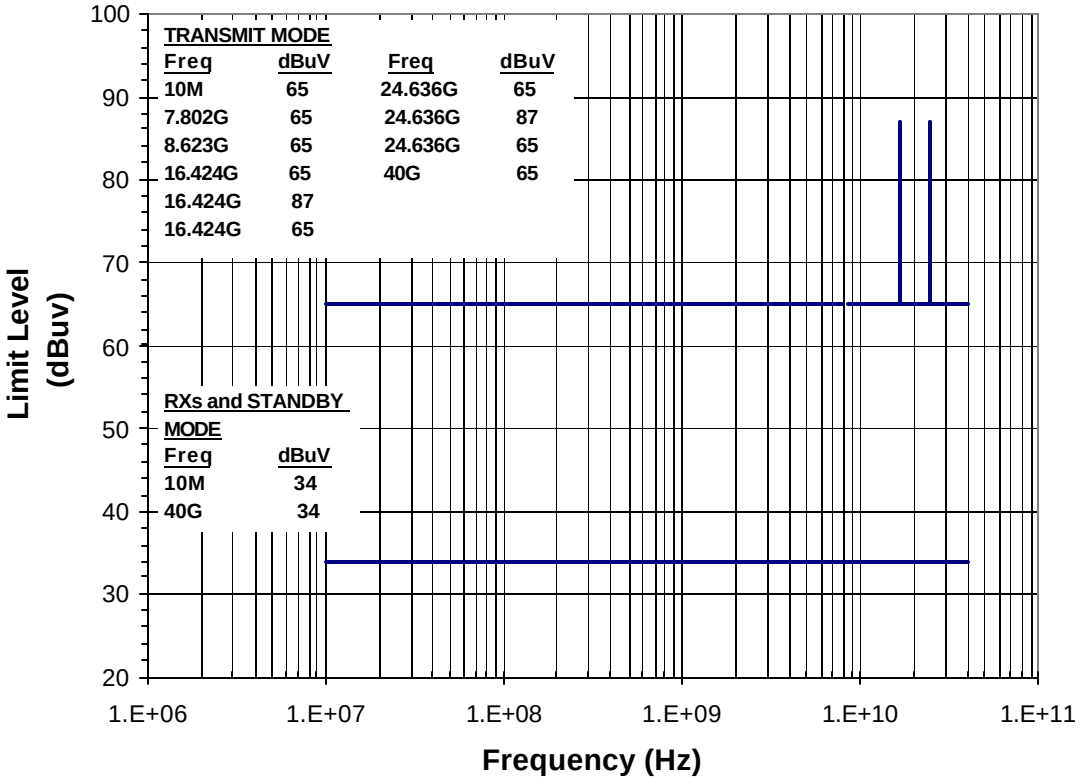


Figure 6-13. X-Band Emissions: CDA SMD 8.212 GHz (CE106) (TBD)

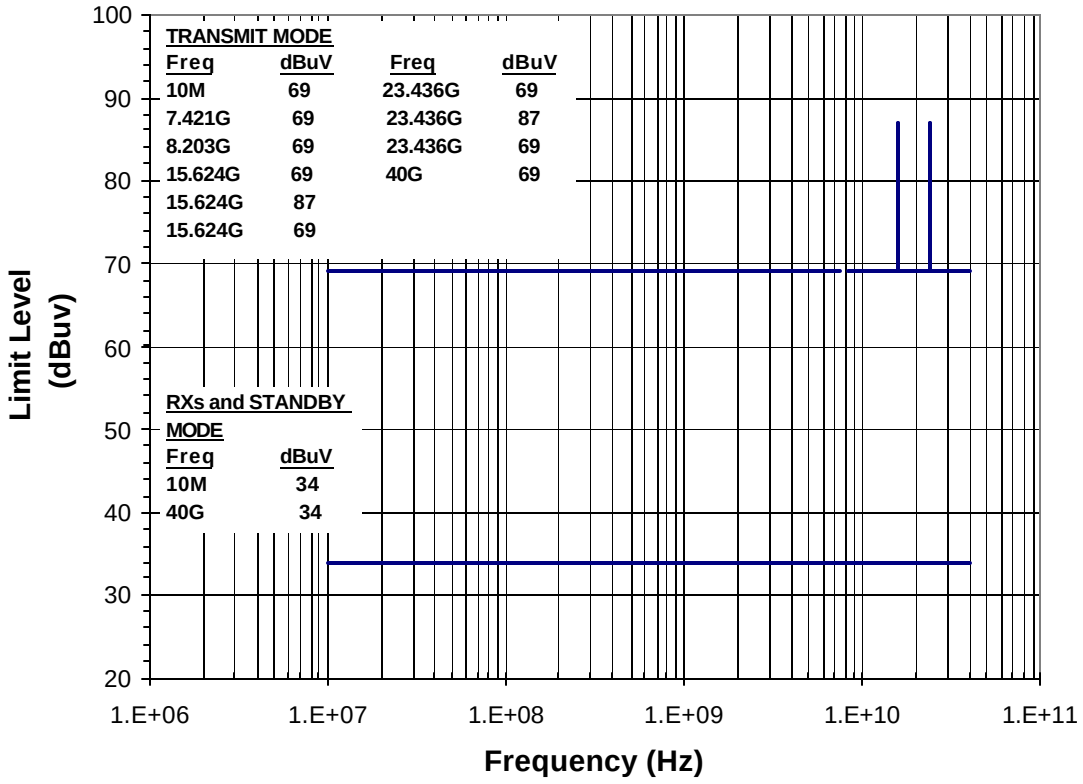


Figure 6-14. X-Band Emissions: HRD DB 7.812 GHz (CE106) (TBD)

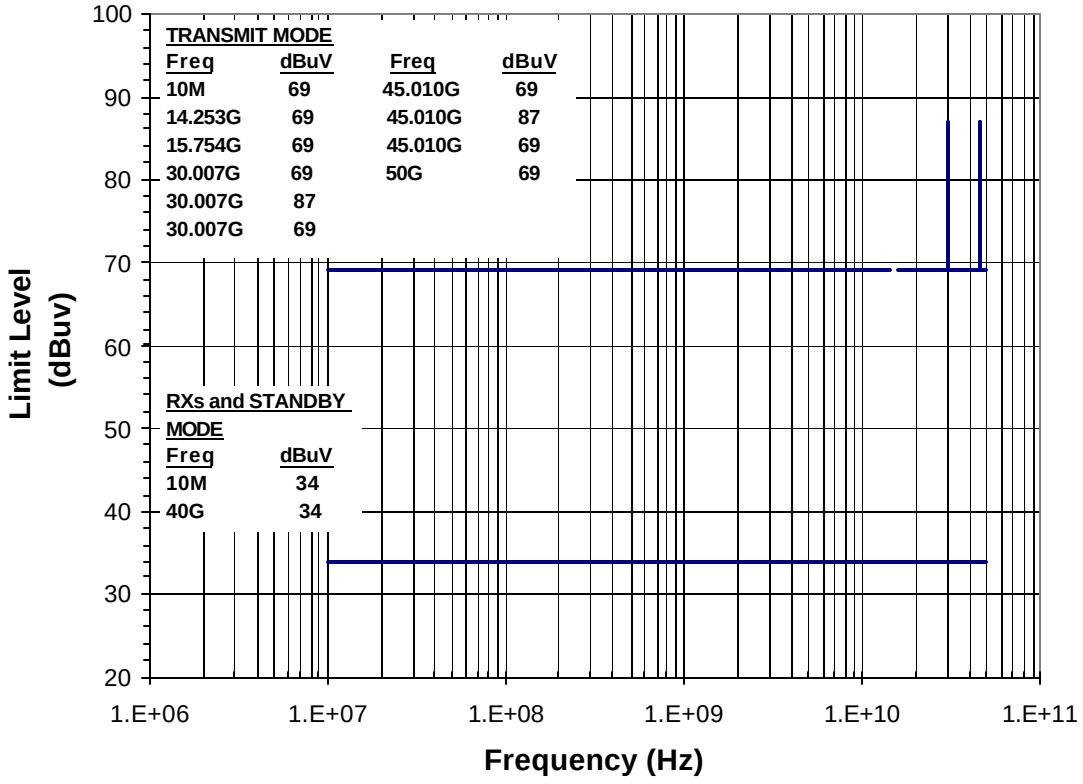


Figure 6-15. Ku-Band Emissions: SN SMD 15.0034 GHz (CE106) (TBD)

7.0 ELECTRICAL GROUND SUPPORT EQUIPMENT (EGSE)

Electrical Ground Support Equipment EMI requirements are as follows.

All EGSE shall be designed to best commercial practices with the following exceptions:

a. EGSE which is powered during Satellite EMI testing and cannot be located at least 60 feet away shall meet the Satellite requirements for RE101, RE102, RS101, and RS103. This requirement is also applicable to all interface cables that connect to the Satellite.

b. EGSE physically located on the Mobile Service Tower shall be designed to meet the requirements of MIL-STD-461E with the following relaxation: LCD and CRT type displays shall not be permanently degraded by the application of RS102 test signals and shall resume normal operation after removal of applied test signals.

c. EGSE that provides primary electrical power to flight hardware shall not exceed the conducted emissions and/or ripple and noise limits defined in the Satellite EMI Requirements Document, GSFC 429-01-07-07, and specified for the EGSE in the applicable requirements documents.

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8.0 EMI/EMC CONTROL

8.1 ELECTROMAGNETIC COMPATIBILITY ADVISORY BOARD

The NPP Project Office will establish an Electromagnetic Compatibility Advisory Board (EMCAB). The EMCAB shall be a formal assembly of the Goddard Space Flight Center (GSFC) NPP Project Office, the NPOESS Integrated Program Office (IPO), the spacecraft contractor, instrument providers, and, when necessary, the subcontractors and vendors.

8.1.1 Purpose

The EMCAB shall ensure that the EMI requirements, as put forth in this document, are carried out in the design implementation and assist in achieving electromagnetic compatibility among similar or dissimilar systems, subsystems, and equipment.

8.1.2 Responsibilities

The EMCAB shall be responsible, as a minimum, for the following:

[a] Perform technical evaluations of the EMI/EMC Program status and concerns,

[b] Determine possible solutions and recommend the most suitable corrective action to the proper management,

[c] Review the effects of the recommended action,

[d] Continue reviewing and updating the EMI/EMC Program,

[e] Ensure communications between EMCAB members and their organizations,

[f] Review and recommend disposition of EMI/EMC documents including Control Plans, Test Plans, Test Reports and Analysis Reports,

[g] Evaluate and recommend disposition of Engineering Review Board (ERB) and Change Control Board (CCB) waiver and deviation requests,

[h] Implement processing of the recommended actions by the proper management,

[i] Coordinate EMI/EMC issues/activities with all other areas of the Project, and

[j] Generate EMCAB-related schedules and update as necessary.

8.1.3 EMCAB Chair

The NPP Project Office will appoint a GSFC Representative to chair the Board with participation by the organizations stated in section 8.1.

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9.0 DEFINITIONS AND COMMONLY USED TERMS

9.1 GLOSSARY

The following terms are defined to facilitate specification of the ground, return, reference and bonding requirements:

Bond:	A low-impedance electrical connection between two conductive elements.
CE101:	Conducted Emissions, Power Leads, 30 Hz to 10 kHz
CE102:	Conducted Emissions, Power Leads, 10 kHz to 10 MHz
CE106:	Conducted Emissions, Antenna Terminals 10 kHz to 40 GHz
CECM:	Conducted Emissions, Common Mode, 30 Hz to 50 MHz
Chassis Reference:	The point within a component at which signal reference and secondary power return leads are referenced to the component chassis.
Component:	A generic term used to describe independently packaged electronics.
Chassis:	The metal enclosure which shields electronic circuits.
CS101:	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz
CS103:	Conducted Susceptibility Antenna Port, Intermodulation, 15 kHz to 10 GHz
CS104:	Conducted Susceptibility Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz
CS105:	Conducted Susceptibility Antenna Port, Cross-Modulation, 30 Hz to 20 GHz
CS116:	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10kHz to 100 MHz
Equipment:	A generic term used to describe independently packaged components and subsystems. A group of components which work together and whose operation is interrelated are also categorized as equipment.

Equipment Chassis:	The metal enclosure which shields the Equipment's electronics.
Ground Plane:	The local electrically conductive surface to which a component is bonded.
Instrument Chassis:	The metal enclosure which shields the instrument's electronics.
Instrument Ground Connection:	The electrically conductive surface or virtual ground point to which all instrument components and its accommodation equipment are bonded.
Intentional Emissions:	The signal or spectrum of emitted energy that is the fundamental purpose of operation. Example: The RF output of a transmitter is an intentional emission at the transmitting antenna, while leakage of the transmitter output from the case of the transmitter is an Unintentional Emission. See Unintentional Emission.
Isolated Secondary Power:	A secondary power source whose loads are completely isolated from instrument to Spacecraft interface electronics.
Primary Power Reference:	The point on the Spacecraft where all primary power returns are referenced. The Primary Power Reference is the reference point for Spacecraft voltage control.
Primary Power Return:	The isolated 28 V current return lead from the component primary power dc-to-dc converter input back to the Spacecraft primary power distribution point.
RE101:	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz
RE102:	Radiated Emissions, Electric Field, 10 kHz to 18 GHz
RF Signals:	RF Signals are those that require coaxial cable and connections. RF Signals typically have fundamental components above 4 MHz.
RS101:	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz
RS103:	Radiated Susceptibility, Electric Field, 10 kHz to 18 GHz
Secondary Power:	Power that has been derived and isolated from primary power typically by a dc-to-dc converter, and used to power Spacecraft interface or other circuits.

Secondary Power Reference:	The point within the component where all current returns from the secondary power circuits are referenced.
Signal Reference:	The reference within the component for digital and analog signals.
Structure Grounding System:	The Spacecraft conducting plate or other structure to which all ground planes are connected.
Signal Return:	The wire which carries the current of a digital or analog signal back to its source.
Unintentional Emissions:	The signal or spectrum of emitted energy that is a by-product of operation. Internally generated signals that are necessary for operation of a device but are not the specified and desired output are Unintentional Emissions. See Intentional Emissions.

9.2 ACRONYMS AND ABBREVIATIONS

A	Ampere
AC	Alternating Current
AFSCN	Air Force Satellite Control Network
ATMS	Advanced Technology Microwave Sounder
CCB	Change Control Board
CCR	Configuration Change Request
CDA	Command and Data Acquisition
CE	Conducted Emission
CM	Common Mode
CrIS	Cross-track Infrared Sounder
CRT	Cathode Ray Tube
CS	Conducted Susceptibility
CW	Continuous Wave
dB	Decibel
DB	Direct Broadcast
DC	Direct Current
EED	Electro Explosive Device
EGSE	Electrical Ground Support Equipment
EMC	Electromagnetic Compatibility
EMCAB	Electromagnetic Compatibility Advisory Board
EMI	Electromagnetic Interference
EMIRD	EMI Requirements Document
EMISM	Electromagnetic Interference Safety Margin
ERB	Engineering Review Board
EWR	Eastern and Western Range
G	Giga (10^9)
GEVS	General Environmental Verification Specification
GIID	General Instrument Interface Document
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
H	Henry
HRD	High Rate Data
Hz	Hertz (sec^{-1})
IPO	Integrated Program Office
JSC	Joint Spectrum Center
JSC*	Johnson Space Center
k	Kilo (10^3)
LCD	Liquid Crystal Display

M	Meg (10^{6})
m	milli (10^{-3}) or meter
n	Nano (10^{-9})
NEA	Non-Explosive Actuator
NPP	NPOESS Preparatory Project
p	Pico (10^{-12})
PPR	Primary Power Reference
RE	Radiated Emission
RF	Radio Frequency
RS	Radiated Susceptibility
SE	Space Transportation System & Expendable Launch Vehicle
SGS	Structure Grounding System
SMD	Stored Mission Data
SN	Space Network
SPG	Single Point Ground
SSA	S-band Single Access
T	Tesla
TLM	Telemetry
u	Micro (10^{-6})
V	Volt
VIIRS	Visible Infrared Imager Radiometer Suite
W	Watt
WSMCR	Western Space and Missile Center Range
?	Ohm

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